Tropical Timber for Building Materials in the Andean Group Countries of South America

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F.J. Keenan and Marcelo Tejada

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Tropical Timber for Building Materials in the Andean Group Countries of South America

F.J. Keenan and Marcelo Tejada

The views expressed in this publication are those of the authors and do not necessarily represent those of the International Development Research Centre.

Abstract

This publication is a summary of the research that has been done, and of the things that have been learned, in an IDRC-supported project in the five Andean Group countries of South America. The main objective of the project was to develop the technology for using the forest resources of the region as building materials. Activities included the selection and cutting of trees in the forest, wood anatomy, species identification, drying, preservation, workability, mechanical properties, grading, derivation of allowable stresses, establishing standard sizes of lumber, the strength of joints and fastenings, the design and testing of structural components, building design, long duration load tests, dynamic testing, the construction of prototype housing, technology transfer, education, and training.

Emphasis is given to the principles and approaches developed in the project that could be transferred to similar projects in other parts of the world. Also included is a list of publications produced by the researchers and consultants.

Résumé

Cette publication est un résumé des travaux qui ont été réalisés et des résultats qui ont été obtenus dans le cadre d'un projet subventionné par le CRDI dans les cinq pays andins de l'Amérique du Sud. Le projet avait pour principal objectif de mettre au point la technologie qui permettrait d'utiliser les ressources forestières de la région comme matériaux de construction. Les travaux ont porté notamment sur la sélection et l'abattage d'espèces forestières, l'anatomie et l'identification des bois, le séchage, la préservation, les propriétés d'usinage, les propriétés mécaniques, le classement, le calcul des contraintes admissibles, l'établissement des dimensions communes des bois d'oeuvre, la solidité des joints et des assemblages, le plan et l'essai des composantes structurales, les modèles de construction, les essais de charge vive de longue durée, les essais dynamiques, la construction de prototypes d'habitation, le transfert de la technologie, l'éducation et la formation.

L'ouvrage présente surtout les théories et les méthodes mises au point qui pourraient s'appliquer à des projets semblables dans d'autres parties du monde. Il comprend également une liste des publications des chercheurs et des consultants.

Resumen

Esta publicación es un resumen de la investigación hecha, y el aprendizaje resultante, en un proyecto aprobado por el CIID en los cinco paises suramericanos des grupo Andino. El objetivo principal del proyecto era desarrollar la tecnologia para utilizar los recursos forestales de la region como material de construcción. Las actividades involucraron la selección y corte de árboles en el bosque, la anatomia de la madera, la identificación de las especies, el secado, la preservación, la trabajabilidad, las propiedades mecánicas, la clasificación de las tensiones, el establecimiento de tamaños normalizados de madera, la fortaleza de las uniones y amarres, el diseño y prueba de los componentes estructurales. El diseño de construcción, las pruebas de carga a largo plazo, las pruebas dinámicas, la construcción de viviendas prototipo, la transferencia tecnológica, la educación y la capacitación.

Se hace énfasis en los principales enfoques desarrollados por el proyecto que puedan ser transferidos a proyectos similares en otras partes del mundo. Se incluye igualmente una lista de publicaciones producida por los investigadores y los consultores.

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PREFACE

In comparison with those of Southeast Asia and Africa, the tropical rain forests of Latin America are even more heterogeneous in that they contain a large number of different species but a relatively low volume of any one species per unit area. A very small percentage of the standing timber volume is harvested and much of the residual forest is damaged or totally destroyed to clear the land for other uses. This deleterious practice of removing only the choice species, and often utilizing only the best logs of the trees that are cut, is extremely wasteful. It is highly desirable to change this situation to achieve greater social and economic benefits from the tropical forests of the Andean subregion.

The building industry provides by far the most important market for timber products. The only way to make a significant breakthrough in tropical-timber utilization is to penetrate this market. Because practically all forest-products research in the past has been carried out in the developed countries, little has been done to expand the technology of tropical timbers for other than decorative purposes. The main purpose of this project was to develop the technology to use tropical woods as structural materials in construction.

Finding out that some tropical species have good technological properties does not mean that they will automatically be accepted by the market. The reasons for uneven utilization of tropical species are as complex as the heterogeneous forests themselves. A good start has been made and there is now a scientific base that will allow the Andean countries to take further action to ensure better utilization of their forest resources.

The research approach followed in this project was carefully reviewed at a meeting attended by research leaders of the participating laboratories and a small group of highly competent forest products experts. Although the project was qualified as ambitious and costly, it was found to be soundly conceived and perfectly justified because of the lack of scientific knowledge available in this field. An attempt was made to make use of the latest techniques to collect reliable data and to evaluate the technological properties of tropical timbers according to their potential end uses.

This project was the first major research activity ever undertaken by the Junta del Acuerdo de Cartagena (JUNAC) and an endeavour of this magnitude, involving 5 countries and 11 institutions, could not be carried out without difficulties. In spite of the problems, the project has been largely successful and it has received political and financial support of all participating countries. The ministers of agriculture of Andean countries have enthusiastically endorsed the project and provided funds for research and construction of prototype dwellings in their respective countries. Support was also received from other sources for laboratory equipment and for the development aspects of wood housing in the subregion.

In addition to generating useful data, this concerted effort has considerably strengthened forest-products research capability in the subregion. Young researchers have been trained, and new forest-products research laboratories have been established in three countries. These national institutions can now undertake additional research needed to increase the number of usable tree species in each country.

This project is an excellent model of international cooperation, which should be strongly encouraged for the development of suitable technologies in developing regions. It is a remarkable achievement and the merit must be given to the young and dedicated researchers who persevered in their tasks.

IDRC is grateful to the authors of this report who agreed to prepare this summary in English for wide distribution. We hope that it will be of interest to the scientific community, and of practical use to the developing regions of Africa and Asia.

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Ing. Marcelo Tejada is the Director of PADT-REFORT (Andean Projects of Technological Development in the Area of Tropical Forest Resources) of the Junta del Acuerdo de Cartagena (the Technical Secretariat of the Andean Pact Commission).

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The contributors are all professionals - engineers, architects, and wood technologists - who are, or were, working in the Wood Technology Project. Their contributions are in several forms: they have coordinated and executed the research described in this publication, they have written reports upon which this publication is based, they have reviewed various drafts of this publication, and they have made innumerable valuable suggestions for its improvement.

The authors would also like to acknowledge the contributions made to the project by other IDRC consultants, particularly Martin Chudnoff, Dr Walter Kauman, Harry Booth, and Borg Madsen.

All photographs are by F.J. Keenan with the exception of Figures 11, 12, and 13, which were provided by Ana Maria Sibille de Parraga.

INTRODUCTION

Andean Group Countries

The Andes mountains of South America rise in the north in Venezuela, run through Colombia, Ecuador, Peru, Bolivia, and down along the border between Chile and Argentina to the southern tip of the continent. In addition to the mountains, these countries share two other features - a Spanish colonial heritage and national technological bases that are less developed than in other parts of the western hemisphere. Five of these countries - Venezuela, Colombia, Ecuador, Peru, and Bolivia - have joined together into an organization called the Andean Group (or the Andean Pact countries) in the hope that cooperative efforts among the countries will yield technological achievements that are not individually possible. The agreement was signed in the city of Cartagena in Colombia, and, thus, the technical secretariat that administers the joint interests of the Andean Group is called the Junta del Acuerdo de Cartagena (or JUNAC) and is headquartered in Lima, Peru. Chile was one of the original partners of the group, but its membership was short-lived.

Forest Resource and its Utilization

The Andean Group subregion has been blessed with rich and extensive forest resources that cover some 220 x 10^6 ha. These stands - almost entirely hardwoods - are highly diverse: in the natural forests, there are estimated to be approximately 2,500 tree species. This great resource, however, is being diminished. There are several causes. The most critical appears to be uncontrolled destruction of the forest by migrants for conversion to agricultural land; in many cases this leads to rapid depletion of soil nutrients and to erosion, rendering the land unfit either for continued agricultural use or for reforestation.

Wood is taken indiscriminantly from the forest for fuelwood. Plans for hydroelectric power generation projects include the possibility of submerging extensive areas of forest. Many species have been selectively and extensively harvested for premium uses like decorative veneers and plywood, fine furniture, and parquet. Of these, some (Chanul, Guayacan, Balsamo, Cedro, and Caoba are good examples) are not readily reforested. Moreover, forest utilization in many parts of the subregion is characterized by waste. This appears in a number of forms: the less-preferred species are left unharvested to die and rot in the forest, about 40% of the harvested tree (tops, limbs, branches, stumps) is left in the forest, and much of the logs, another 30-40%, is unused mill residue in the forms of slabs, edgings, trims, veneer clippings, sawdust, and shavings (Fig. 1). Another form of waste results from the fact that most wood products are in a relatively simple form - logs, sawn timber, veneer, and plywood, but it is possible, with further processing, to add more value to the products and to earn more from the same volume of wood.

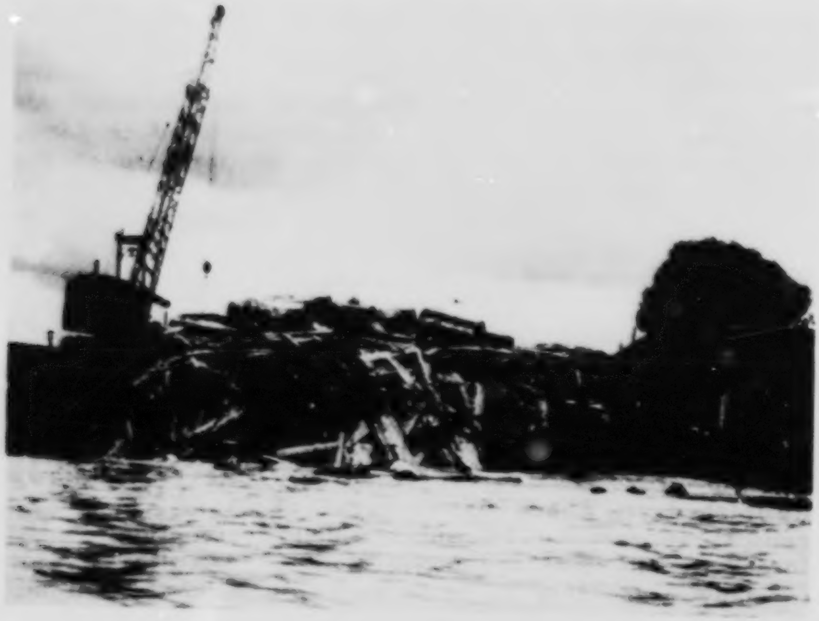

Fig. 1. An example of unused mill residue.

Paul Richards, writing in the Scientific American (Richards 1973) summarizes the global danger in these words: "One of the oldest ecosystems and a reservoir of genetic diversity, the wet evergreen tropical forest is threatened by the activities of man and may virtually disappear by the end of the 20th century."

In the subregion, the situation is possibly not as bleak as Richards suggests. The problem is clearly recognized both by JUNAC and by international aid agencies like the International Development Research Centre (IDRC) and the Canadian International Development Agency (CIDA). Several projects in silviculture, forest management, agroforestry, and afforestation are currently under way and many more are planned for the future.

Although there is a historical precedent for the use of wood in major public buildings and in the grander private residences, wood is currently regarded as "the poor man's building material" or, at best, a temporary building material in the subregion. Consequently, where wood is used today in construction, it appears without benefit of professional design and, thus, is generally not resistant to the effects of earthquakes, fire, and deterioration by insects and decay fungi. Compounding the problem are shortages of engineers, architects, and craftsmen trained in the proper use of tropical woods in construction and shortages of courses and training programs that would help create a wood-construction infrastructure. Nor, by and large, has there been any decisive action on the part of the governments, the financial institutions, or the forest products industry to support the development of engineered wood products in construction. Ironically, the problem of an underutilized and renewable resource of construction materials exists in a part of the world plagued by chronic shortages of adequate housing.

It is not possible to stop the exploitation of the forest. It is possible, however, to use it more wisely and with greater benefit to society. This was the fundamental objective of JUNAC when it proposed the wood technology development project that is the subject of this publication.

The Project

The earliest major project that involved all five countries of the Andean Group was the "Estudio Integral de la Madera para Construcción" (Comprehensive Study of Wood for Construction) or simply "the Project." It was one of a group of four studies under the acronym PADT-REFORT (Proyectos Andinos de Desarrollo Tecnológico en el Area de los Recursos Forestales Tropicales/Andean Projects of Technical Development in the Area of Tropical Forest Resources) and was proposed in response to the problems outlined earlier (Tejada 1981). The objective of the Project was to introduce wood as a construction material into the national economies to provide solutions to the housing problem. This was done by determining all of the technological properties of 105 tropical hardwood timber species from the forests of the subregion and by utilizing this new technology in the design and construction of wood buildings. For this project JUNAC sought and received financial support from IDRC.

Under the ultimate authority of JUNAC, a Contracting Committee (consisting of the Forestry Directors of each country plus an Executive Secretary who is a JUNAC official) directed the technical and administrative aspects of the Project. There is also a National Director in each country responsible for contracting his or her country's share of the research to university or government research laboratories. Activities are coordinated through a technical group within JUNAC.

The Project has two phases. The first deals with the technological basis for using wood as a construction material, and the second will complete the development cycle by designing and constructing more than 100 houses in each of the five countries, including the establishment of a prefabricated housing industry.

The achievements of the 11 subregional laboratories and over 200 workers in the Project have been substantial. In the following chapters, the various components of the Project are described and many of the things that have been learned are outlined. It is the hope of the authors, contributors, and sponsors of this publication that researchers in other countries can take advantage of what has been accomplished in this Project.

APPROPRIATENESS OF WOOD AS A BUILDING MATERIAL

Since the time when early man first propped some tree limbs against a rock to form a shelter from the weather, wood has been used as a building material. It is a material that offers many advantages (and some disadvantages) to the user. Among its better features are that it is one of our very few renewable building materials; it requires much less processing energy per unit of weight than steel, aluminum, or concrete; it provides much better thermal insulation per inch of thickness than the metals or concrete; it has higher ratios of strength and stiffness to weight than the other major materials; it is relatively easy to work and to join requiring only simple tools; and in certain circumstances it has high durability. However, there can be some disadvantages to using wood, and any wood-utilization program must consider these problems, e.g., wood burns, it rots, it shrinks when drying, it is vulnerable to insect attack, and it can be more expensive than other materials.

Because of wood's manifold advantages, there is often a temptation in a wood-utilization program to develop wood construction for situations where it cannot be justified. It is, therefore, useful to reflect on the appropriateness of wood construction in various situations in the Andean subregion. In doing this, one could review what building materials are presently being used, and ask whether or not manufactured wood products (sawn lumber, plywood, particleboard) would be feasible and appropriate replacements for the current building materials. Various geoclimatic zones can be examined and separate attention given to urban and rural locations and to high- and low-income occupants.

Peru, for example, is generally considered to have three main geoclimatic zones: desert, sierra, and jungle. According to Teng (1971):

> The whole of Peru's western seaboard along the Pacific coast is desert and this region constitutes one ninth of the country. One third of the population is concentrated in the desert, which is the economic heart of the country. From the coastal shelf the Andes rise steeply to a high sierra. This is composed of massive groups of high mountains and deep canyons. Only the land in the deeper valley basins is farmed and most of the sierra is covered with grass and shrubs. More than half of the population inhabit this sierra, which covers one fourth of the land area of the country. The eastern slopes of the highlands are composed of densely forested mountains and ravines. At the foot of the mountains lie the vast jungle lands of the Amazon basin. These constitute some 60 percent of the area of the country but are inhabited by only 10 percent of the population....In the coastal region, temperatures are moderate and precipitation is very low, while in the sierra the climate is hot with very little rainfall on the lower slopes and changes with the altitude until in the highest part of the region it is extremely cold. The jungle region is characterized by a hot, wet climate with very high precipitation.

In the jungle, the typical shelter built by the Indians is a pole frame structure having a living platform raised clear of the ground and with a steeply pitched roof made of palm leaves or thatch (Fig. 2). The poles are fastened together using vines. This type of shelter seems to be perfectly in balance with the combined needs for ventilation, drainage, and protection from rain and from the ground. It is readily constructed from the materials at hand, costs little (if anything), and is adequately durable for a seminomadic life-style based on hunting, fishing, and shifting agriculture. Houses made of manufactured wood products (boards, planks, joists, plywood, etc.) are clearly not applicable to this segment of society.

However, the picture is different for communities in the jungle that are organized and more permanent. One tends to see a great mixture of building materials

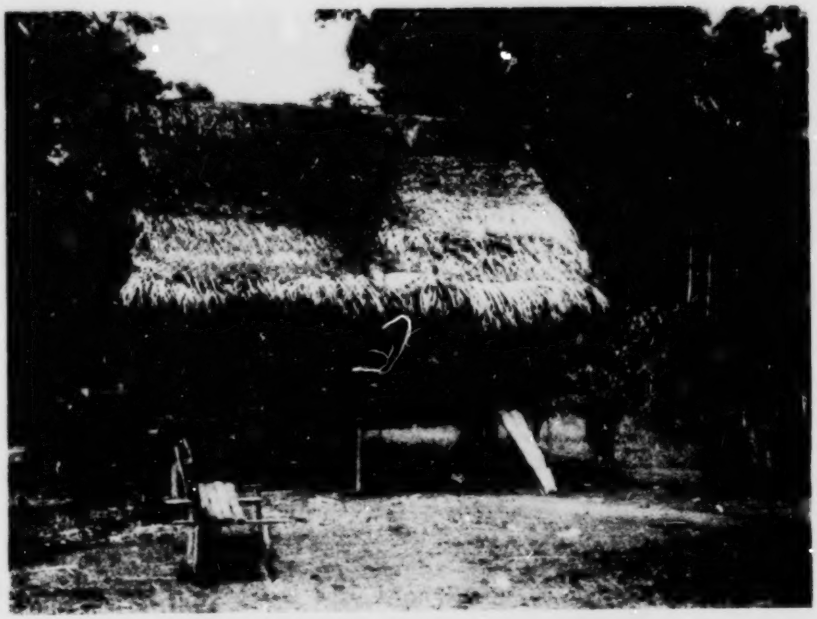

Fig. 2. A rural pole frame structure.

in the large towns in the jungle: concrete, adobe, plaster, brick, steel, lumber, poles, palm, and thatch. Manufactured wood products are seen here in all forms. In the shanty areas, poverty causes wood waste such as sawmill slabs and edgings and veneer mill clippings to be used as roof and wall coverings. On the other hand, it is possible to see some well-designed houses that have the same overall architectural style as the "jungle clearing" house, i.e., a steeply pitched roof covered with palms or thatch, and a raised living platform, but with the walls and floor of sawn lumber, possibly treated with preservatives. This urban modification has provided more permanence and more privacy but has incorporated a large amount of verandah space for ventilation and for the opportunity to retain the "sheltered outdoor" life-style.

For this type of structure, the cooking area is often in a separate building some distance away and downwind from the main house for fire protection. Toilet and washing facilities are similarly often in a separate building. This appears to be a feasible, and appropriate, use for sawn lumber in housing; it is in an area where wood is abundant and where there are sawmills. It is, therefore, the natural material for the site and should be economically competitive. However, it is also clear that the successful use of wood here will benefit from wood technology: the species chosen must possess natural resistance to insect attack or be capable of being readily treated with preservatives; the design and detailing of the house must be such that moisture will not be trapped and lead to fungal attack; the species chosen should also be of low enough density that it can be nailed without splitting.

Some years ago, a very fine reinforced concrete tourist hotel was built in Pucallpa, a large forest products town in the Peruvian jungle. However, apparently when the building was finished, it was unusable because it was too hot inside: the concrete roof didn't keep out the heat. Consequently, a second roof - this one made of lumber - was built on top of the concrete roof. Because of the good thermal insulating value of wood (and the air circulation provided under the second roof), the hotel is now very comfortable.

In the sierra, there has never been a tradition of wood construction except for relatively minor uses. Before the Spanish conquest, the Incas had brought the art of stonemasonry to the highest levels. The Spaniards continued the tradition of using stone for their major structures in the sierra, largely by making use of the talents of the enslaved Incas. To the present day, stonework is used for government buildings and for the houses of the more affluent in Peruvian society.

For the low-income groups the construction materials are adobe for the walls, and wood poles (round or partially hewn) for the roof framing, with a roof covering of tiles, thatch, or corrugated metal (Fig. 3 and 4). Hewn wood pieces also appear as lintels over windows and doors; these are often extended around the full periphery of the house to provide a horizontal tying action for the adobe in case of earthquakes (Fig. 5). The men of the sierra are skilled at building a house of adobe walls, and they can use the materials that are free on the land - mud,

Fig. 3. A house with adobe walls and a timber (Eucalyptus) roof in the sierra.

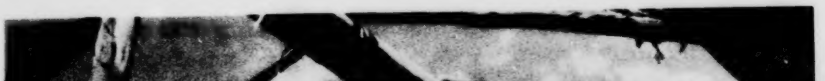

Fig. 4. Eucalyptus roof members used in the sierra.

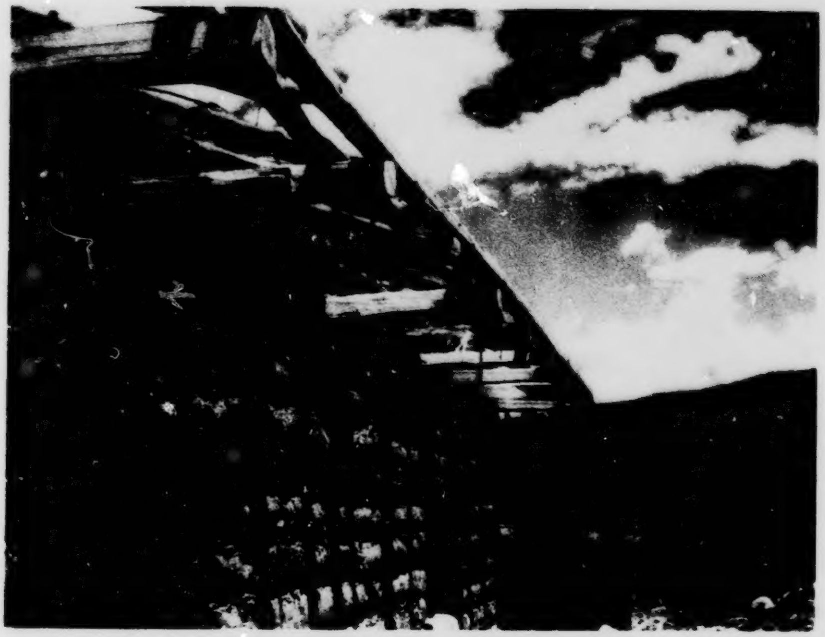

Fig. 5. Eucalyptus eaves and lintels as used in the sierra. The lintel continues around the house to provide a tying action for the adobe during earthquakes.

straw, water, and sun. It doesn't seem to be sensible, economically, to replace the adobe with lumber (even though wood construction can have a much better resistance to earthquakes). Unless the government transports the lumber from the sawmills in the jungle up to the sierra, provides it, the tools, the nails, and the technical advice free to the occupants, it is difficult to see why wood would be used in place of adobe for the walls of these houses.

The species of wood most commonly used for roof construction is Eucalyptus because of its availability in the sierra. However, Eucalyptus is hard to dry and to saw. Therefore, young trees are felled and these are used as poles, rather than being sawn into lumber. The resulting size is often larger than is necessary, and this increases the inertial mass of the roof, making it more susceptible to seismic damage. In this case, if wood technology were to lead to a reduction in the size of the roof timbers, this could simultaneously lower the cost of the roof as well as reducing the danger of earthquake damage to the walls.

One feasible and current use for wood in the sierra (and to some extent elsewhere) is for buildings for military camps and for mining, roadbuilding, irrigation, and forestry camps, i.e., structures that are suited to prefabrication, packaging, easy and quick transportation and erection, and possible reuse at another site later. Because of its relatively light weight and good workability, wood is ideally suited for such structures and has been used in this way for many years. Once again, continued success in this area will depend upon the results of research and development activity using the tropical hardwoods of the area.

Finally, in the desert regions (and in particular the river valleys that cut across the coastal plain), rural and urban areas can be considered separately. In the rural areas, the materials for low-income housing are mud, sticks, adobe, and also woven panels made of split cane supported on wood pole frameworks (Fig. 6). The cane is free, or at least cheap, is locally available on the land (quite abundantly in some valley locations), and provides both ventilation and protection from sun, sand, and wind. This type of housing accompanies a rather primitive life style; however, it is really the lack of amenities that renders the life-style primitive, not the house itself.

The urban areas have actually seen a decrease in the importance of wood as a building material over the years. In colonial times, many churches and cathedrals were constructed of stone but with heavy timber roofs. Several large public buildings used timber for the columns and the roofs. One outstanding example is the bullring in Lima that was built in 1768. Although founded on adobe, everything else is wood - the seats, columns, and roof. This gives an excellent testimonial to the possibility of using wood to build for permanence in an area of high earthquake activity.

A second important historical use of wood was in the form of "quincha" (or "bahareque" or "bajareque," names that hint at its Moorish origin). Quincha was

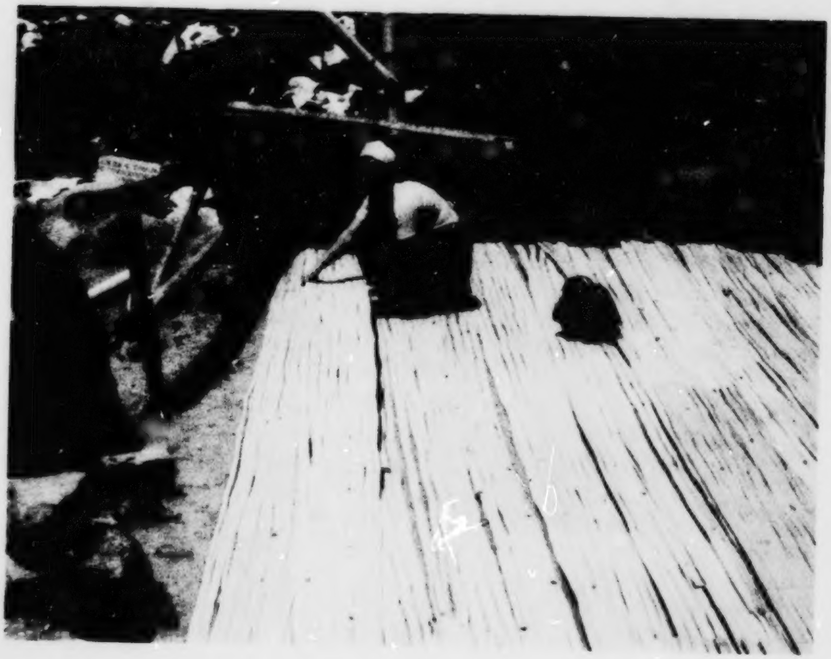

Fig. 6. In the desert, split cane, as shown here, is woven into wall and roof panels.

used largely for walls and consisted of long vertical wood studs, spaced less than 2 feet apart, with diagonal braces at the lower end, and with split cane attached perpendicular to the studs. Mud and/or gypsum was then applied to the split cane. A common form of construction consisted of two-storey buildings, of which the lower storey had adobe walls and the upper storey walls were quincha. This system was often used in conjunction with timber columns, verandahs, and roofs.

Today, the modern commercial and government buildings are of reinforced concrete, specially designed to be earthquake-resistant and fireproof. Industrial buildings use steel and brick also. Private homes of the affluent use concrete, brick, and tiles, and sometimes wood, but mainly for architectural reasons. For the lower-income groups, the housing materials are mainly brick, with some adobe, stone, concrete, and gypsum. Although bricks are quite inexpensive, a labourer will be able to buy only a few at a time and his house-building progress will be slow; in fact, with the virtual absence of precipitation in Lima, he may never have a permanent roof on his house! However, from a sociological point of view, every brick that is worked for, purchased, and laid, represents a very tangible step in a man's building of a better life for himself and his family. At the present time, wood is more expensive than bricks, largely because of the great distances that it must travel from the jungle over the mountains to the coast, and also because of the unstable nature of the wood market caused by the transportation problems in the jungle due to the rain and the lack of roads. Another reason not to use wood in the crowded low-income urban areas is the risk of fire, particularly when one considers how poorly equipped many firefighting forces are.

Nevertheless, the pressures to provide large amounts of new housing in the vicinity of Lima are very great, and the need is urgent. Lima's population is growing rapidly because of the large-scale migration of workers and their families from the sierra. Brick construction is slow - in some cases, much too slow - and the more rapidly constructed wood houses are needed in spite of a cost disadvantage. Consequently, a number of companies and government organizations have been building prototype wooden houses in Lima (Fig. 7), but these suffer from two disadvantages: they are not affordable by the lowest-income group in urban society, and their design and construction have not fully utilized the benefits obtainable from wood technology and construction technology.

This form of construction is adaptable to low-rise buildings for tourism; Fig. 8 shows a wood-frame extension to the tourist hotel at Machu Picchu, Peru.

All of the foregoing pertains to housing, but wood can be a highly appropriate material for engineered structures such as buildings for industrial, commercial, or public assembly purposes; bridges; water towers; earth-retaining structures; cribs; wharves; electricity and communications towers; agricultural storage buildings; and concrete falsework and formwork. These uses of wood occur throughout the country but primarily on the coast and in the mountains. If the

Fig. 7. Prototype wood housing in Lima, Peru.

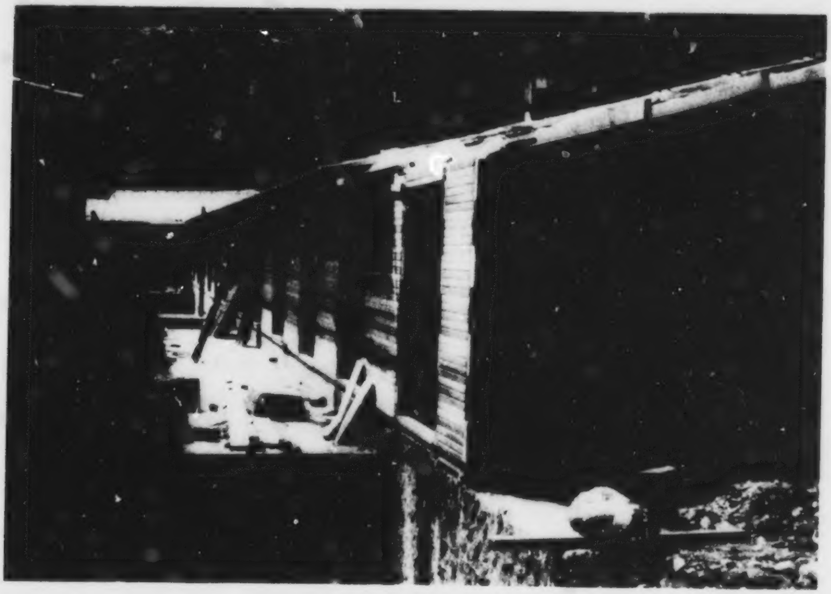

Fig. 8. The extension to the Tourist Hotel at Machu Picchu, Peru.

subregion's forest resources can be developed to produce wood products suitable for engineered construction, this will be to the economic benefit (and thus to the social benefit) of the people of those countries.

SAMPLING THE FOREST RESOURCE

Subregional Forests

The subregional forests, which are drained mainly by the Orinoco and Amazon river systems, cover approximately 60% of the land area of the subregion and comprise some 221 x 10^6 ha (Table 1). As mentioned in the introductory remarks, there are estimated to be 2,500 tree species in the highly hetergeneous natural forests. Of these, only about 1,000 have been botanically identified (Dourojeanni 1981) and only about 50 species are regularly used by the wood industry. In the Barrancabermeja area of Colombia, for example, in an area of 375,000 ha there are 260 known forest species, of which 21 are recognized commercially but only three are regularly harvested. As another example, in Peru in 1979, some 170 species were used for industrial purposes but nine of these species represented more than 75% of the lumber, laminated wood, and plywood in this region (Peru 1980).

Table 1: Areas of Tropical Forests in the Subregion

Country	Forest area (10^6 ha)	% coverage of the country
Bolivia	45	43
Colombia	50	64
Ecuador	13	83
Peru	65	65
Venezuela	48	54
Total	221	

Source: FAO (1972).

This variety brings with it another important characteristic - the very low representation of each species by unit of area. It is common to find, therefore, on the one hand, barely 1-8 specimens/10 ha and, on the other hand, as many as 50-80 different species per hectare. The maximum number of trees of the same species per hectare is in general less than 10 (Dourojeanni 1981).

Forest utilization in the Amazon is, therefore, extraordinarily selective. For several decades the interest has been solely in species of great world prestige, such as cedar (cedrela) and mahogany (swietenia) and, although the tendency is clearly toward a larger number of species, the process is still slow (Dourojeanni 1981).

This practice, also known as "highgrading" or "cut and get out," entails the removal of desirable species leaving behind the inferior, unhealthy, or undesirable species to take over the area. It has been estimated that, during the selective harvesting of 10% of the trees in the rain forests of Malaysia, 55% of the remaining trees are severely damaged or destroyed and that only 35% are left undamaged (U.S. Interagency Task Force on Tropical Forests 1980). It can be assumed that similar damage occurs in the subregional tropical forests under present logging practices.

The harvesting process begins with felling, which is mainly carried out with chainsaws (Leigh 1984). The use of axes, common a decade ago, is disappearing. Before a tree is felled it is cleared of vines and shrubs with machetes. Once felled, the crown is topped and the butt bucked if flare is extreme. The main stem is then bucked to appropriate dimensions, eliminating defective or damaged parts, so that it can be handled by the available hauling system. The crown, butt, and severed parts are left at the stump.

According to Leigh (1984), primary transport is either manual or mechanized. Manual methods are labour intensive. In the lowlands, logs are either rolled along the ground or floated through flooded areas toward the nearest river. Hauling distances rarely exceed 2 km. On mountain slopes chutes are constructed in gullies to slide logs down to the roadside.

Construction of the chute is simply a matter of clearing a gully and positional small logs to act as ramps in the difficult parts of the tract. For mechanized primary transport, in lowland areas with good load-bearing soils, the common piece of equipment is the wheeled skidder. Skidding distances average 2.5 km but skids up to 10 km are frequent. On the eastern flank of the Andes Range a combination of wheeled skidders and crawler tractors is preferred. Crawler tractors usually build the skid roads and often position themselves behind the skidder's load to assist the skidder up steep slopes. Old rebuilt trucks with A-frames and winches are also common. Mechanized skidding operations are limited to the dry season.

Secondary transport is mainly by river in the lowlands. The logs are either dumped into the river and assembled into rafts or loaded on to self-loading barges. In the highlands roads are the only means of transport. Logs are loaded onto trucks manually, or by using skidders and crawler tractors from elevated soil ramps or up planks onto the truck platform (Leigh 1984).

The amount of standing timber in these forests is enormous: 33 x 10^9 m^3 with a possible value of U.S.$ 36 billion (Table 2). Nevertheless, production is

Table 2: Volume of Standing Timber in the Tropical Forests of the Subregion

Country	Standing timber volumes (10^6 m^3)
Bolivia	7050
Colombia	6000
Ecuador	1625
Peru	11100
Venezuela	7185
Total	32960

Source: JUNAC publication "Anexo a la Decisión 89."

Table 3: Timber Production in the Subregion (10^3 m^3)

Countries	Firewood and charcoal	Industrial purposes	Total
Bolivia	4060	490	4550
Colombia	38813	3209	42022
Ecuador	4493	1720	6213
Peru	2866	1480	4346
Venezuela	8236	636	8872
Total	58468	7535	66003

Source: FAO (1981).

low and the contribution of the forest sector to the gross national product (GNP) has not exceeded 0.5% in any of the countries. One of the reasons for this is the high level of noncommercial use as shown in Table 3 where in 1979 almost 90% of the wood harvested in the subregion was used for firewood. Only 1-10 m^3/ha of timber is extracted for industrial purposes and the average is around 3 m^3/ha.

This picture of an underutilized forest resource led the project planners to the conclusion that a much wider range of species should be studied for their potential use in construction. Eventually, 105 species were selected and these are described in the next section.

Selection and Sampling of Species

Tables 4-8 list the 105 species that were studied in this project. Various criteria were used (with varying emphasis in each country) for their selection. Species chosen for inclusion in the study had at least one of the following characteristics:

(a) Species that have an adequate exploitable volume, either presently or potentially;

(b) Species that are conducive to afforestation or reforestation;

(c) Species that exhibit good tree form and size;

(d) Species for which some properties are already known;

(e) Species that already have a tradition of being used in construction and are currently being marketed, either individually or in groups;

(f) Species that do not have an existing higher-value end use for either domestic or export markets, i.e., the so-called secondary species; and

(g) Species that are of medium to low density: although a higher density will give higher strength properties, it usually makes the wood more difficult to saw and nail; moreover, most of the time, the very high strength properties are not needed in house construction. (The high density species are more suitable, for example, as flooring.)

The method of transporting logs also influenced the choice of species to be sampled. For example, in Peru, 95% of the logs traveled by water and, therefore, emphasis was given to the more floatable low- to medium-density woods. Other countries that had better road systems opted for more higher-density woods; Bolivia, for instance, had a road network in place that had been built by the mahogany export industry.

Another constraint on sampling the forest resource is the inadequate inventory of the forest stands. As a result of this combination of inadequate inventory data and of transportation difficulties, there is a great temptation simply to seek out those trees that are closest to the road or river and to disregard all the niceities of forest sampling theory.

Another sampling problem is the site-dependency of species properties. It is known that the variation in properties of a particular species from one site to another can be quite considerable. In the case of one species in Peru, Tornillo, trees coming from one of the sites had a greater preponderance of compression

Table 4: Species of Bolivia

No.	Common name	Scientific name	Family
B1	Ajo ajo	*Gallesia integrifolia* (Spreng) Harms	PHYTOLACCACEAE
B2	Almendrillo	*Taralea oppositifolia* Aubl.	PAPILIONACEAE
B3	Bibosi	*Ficus glabrata* H.B.K.	MORACEAE
B4	Blanquillo	*Buchenavia exicarpa*	COMBRETACEAE
B5	Coquino	*Ardisia cubana* A.B.C.	MYRSINACEAE
B6	Curupau	*Piptadenia grata* (Wild) Macbr.	MIMOSACEAE
B7	Guayabochi	*Calycophyllum spruceanum* (Benth.) Hook.	RUBIACEAE
B8	Kaqui	*Diospyros* sp.	EBENACEAE
B9	Mapajo	*Ceiba pentandra* (L.) Gaertn	BOMBACACEAE
B10	Murure	*Clarisia racemosa* Ruiz et Pavon	MORACEAE
B11	Negrillo	*Persea caurulea* Nez.	LAURACEAE
B12	Ochoo	*Hura crepitans* L.	EUPHORBIACEAE
B13	Pacay	*Inga edulis* Mart.	MIMOSACEAE
B14	Palo maria	*Calophyllum brasiliense* Camb.	CLUSIACEAE (GUTTIFERAE)
B15	Plumero	*Vochysia lanceolata* Staff.	VOCHYSIACEAE
B16	Sangre de toro	*Licania* sp.	ROSACEAE
B17	Serebo	*Schizolobium parahybum* (Vell.)	CAESALPINIACEAE
B18	Tachore	*Poulsenia armata* (Miq.) Standl.	MORACEAE
B19	Verdolago	*Terminalia amazonia* (J.F. Gmel.) Exell.	COMBRETACEAE
B20	Yesquero	*Cariniana estrellensis* (Raddi) Kuntze	LECYTHIDACEAE

Table 5: Species of Colombia

No.	Common name	Scientific name	Family
C1	Aceite mario	*Calophyllum mariae* Planch et Triana	CLUSIACEAE (GUTTIFERAE)
C2	Balsamo	*Myroxylon balsamum* (L.) Harms	PAPILIONACEAE
C3	Bonga	*Ceiba pentandra* L. Gaertn	BOMBACACEAE
C4	Caimito colorado	*Pouteria* sp.	SAPOTACEAE
C5	Canime	*Copaifera* sp.	CAESALPINIACEAE
C6	Caracoli	*Anacardium excelsum* (Bert. et Balb) Skeels	ANACARDIACEAE
C7	Carbonero	*Licania campestre*	ROSACEAE
C8	Carra	*Huberodendron patinoi* Cuatr.	BOMBACACEAE
C9	Cocuelo blanco	*Gustavia speciosa* (H.B.K.) D.C.	LECYTHIDACEAE
C10	Cuangare	*Dialyanthera gracilipes* A.C. Smith	MYRISTICACEAE

C11	Chanul	Humiriastrum procerum (Little) Cuatr.	HUMIRIACEAE
C12	Chaquiro	Goupia glabra Aubl.	CELASTRACEAE
C13	Dormilon	Pentaclethra macroloba (Willd.) Ktze.	MIMOSACEAE
C14	Hobo colorado	Spondias mombin L.	ANACARDIACEAE
C15	Machare	Symphonia globulifera L.f.	CLUSIACEAE (GUTTIFERAE)
C16	Mora	Clarisia racemosa Ruiz et Pavon	MORACEAE
C17	Nato	Mora megistosperma (Pittier) Britt et Rose	CAESALPINIACEAE
C18	OlorosoHu	Humiria balsamifera (Aubl.) St. Hill	HUMIRIACEAE
C19	Pantano	Hieronyma chocoenis Cuatr.	EUPHORBIACEAE
C20	Punula	Quararibea asterolepsis Pittier	BOMBACACEAE
C21	Sajo	Campnosperma panamensis Standl.	ANACARDIACEAE
C22	Sande	Brosimum utile (H.B.K.) Pittier	MORACEAE
C23	Sebo	Virola reidii Little	MYRISTICACEAE
C24	Soroga	Vochysia ferruginea Mart.	VOCHYSIACEAE
C25	Tangare	Carapa guianensis Aubl.	MELIACEAE

Table 6: Species of Ecuador

No.	Common name	Scientific name	Family
E1	Caimitillo	*Chrysophyllum cainito* L.	SAPOTACEAE
E2	Chanul	*Humiriastrum procerum* (Little) Cuatr.	HUMIRIACEAE
E3	Chimi	*Pseudolmedia laevigata* Trec.	MORACEAE
E4	Eucalipto	*Eucalyptus globulus* Labill.	MYRTACEAE
E5	Fernansanchez	*Triplaris guayaquilensis* Aubl.	POLYGONACEAE
E6	Guayacan pechiche	*Minquartia guianensis* Aubl.	OLACACEAE
E7	Jibaro	*Pithecellobium latifolium* Benth et Hook	MIMOSACEAE
E8	Laguno	*Vochysia macrophylla* Stafleu.	VOCHYSIACEAE
E9	Mascarey	*Hieronyma chocoensis* Cuatr.	EUPHORBIACEAE
E10	Moral fino	*Chlorophora tinctoria* (L.) Gaud.	MORACEAE
E11	Pacora	*Cespedezia spathulata* (Ruiz et Pav.) P.	OCHNACEAE
E12	Piaste	*Guarea* sp.	MELIACEAE
E13	Pino insigne	*Pinus radiata* D. Don	PINACEAE
E14	Pituca	*Clarisia racemosa* Ruiz et Pavon	MORACEAE
E15	Romerillo azuceno	*Podocarpus oleifolius* Don in Lamb.	PODOCARPACEAE
E16	Romerillo fino	*Podocarpus rospigliosii* Pilger	PODOCARPACEAE
E17	Sande	*Brosimum utile* (H.B.K.) Pittier	MORACEAE
E18	Seique	*Cedrelinga catenaeformis* D. Ducke	MIMOSACEAE
E19	Tangama	*Parkia* sp.	MIMOSACEAE
E20	Yumbingue	*Terminalia amazonia* (J.F. Gmel.) Exell.	COMBRETACEAE

Table 7: Species of Peru

No.	Common name	Scientific name	Family
P1	Almendro	*Caryocar coccineum* Pilger	CARYOCARACEAE
P2	Cachimbo	*Cariniana domesticaca* (Mart.) Mierc. Trens.	LECYTHIDACEAE
P3	Casho moena	*Ocotea* sp.	LAURACEAE
P4	Catahua amarilla	*Hura crepitans* L.	EUPHORBIACEAE
P5	Copaiba	*Copaifera officinalis* L.	CAESALPINIACEAE
P6	Chimicua	*Pseudolmedia laevis* (R. et P.) Macbr.	MORACEAE
P7	Diablo fuerte	*Podocarpus rospigliosii* Pilger	PODOCARPACEAE
P8	Estoraque	*Myroxylon peruiferum* L.	PAPILIONACEAE
P9	Huayruro	*Ormosia coccinea* Jacks.	PAPILIONACEAE
P10	Huimba	*Ceiba samauma* (Mart.) Schum. in Mart.	BOMBACACEAE
P11	Manchinga	*Brosimum uleanum* Mildbr.	MORACEAE
P12	Maquizapa nagcha	*Apeiba aspera* Aubl.	TILIACEAE
P13	Marupa	*Simarouba amara* Aubl.	SIMAROUBACEAE
P14	Moena negra	*Nectandra* sp.	LAURACEAE
P15	Palo sangre amarillo	*Pterocarpus* sp.	PAPILIONACEAE
P16	Palo sangre negro	*Pterocarpus* sp.	PAPILIONACEAE
P17	Panguana	*Brosimum utile* (H.B.K.) Pittier	MORACEAE
P18	Pumaquiro	*Aspidosperma macrocarpon* Mart.	APOCYNACEAE
P19	Tornillo	*Cedrelinga catenaeformis* D. Ducke	MIMOSACEAE
P20	Ucshaquiro blanco	*Sclerolobium* sp.	CAESALPINIACEAE

Table 8: Species of Venezuela

No.	Common name	Scientific name	Family
V1	Aceite cabimo	Copaifera pubiflora Benth.	CAESALPINIACEAE
V2	Algarrobo	Hymenaea courbaril L.	CAESALPINIACEAE
V3	Apamate	Tabebuia rosea (Bertol) D.C.	BIGNONIACEAE
V4	Baraman	Catostemma commune Sandw.	BOMBACACEAE
V5	Carapa	Carapa guianensis Aubl.	MELIACEAE
V6	Carne asada	Hieronyma laxiflora (Tul.) M.Arg.	EUPHORBIACEAE
V7	Charo amarillo	Brosimum alicastrum (Swartz.) ssp. bolivarensis (Pitt.) C.G. Berg.	MORACEAE
V8	Chupon rosado	Pouteria anibifolia (A.C. Smith) Baehni	SAPOTACEAE
V9	Guayabon	Terminalia guianensis Eichl.	COMBRETACEAE
V10	Mijao	Anacardium excelsum (Bert. et Balb) Skeels	ANACARDIACEAE
V11	Mora	Mora gonggrijpii (Kleinth.) Sandw.	CAESALPINIACEAE
V12	Mureillo	Erisma uncinatum War.	VOCHYSIACEAE
V13	Pardillo amarillo	Terminalia amazonia (J.F. Gmel.) Exell.	COMBRETACEAE
V14	Perhuetamo	Mouriri barinensis (Morley) Morley	MELASTOMATACEAE
V15	Saman	Pithecellobium saman (Jacq.) Benth.	MIMOSACEAE
V16	Sangre de drago	Pterocarpus vernalis Pittier	PAPILIONACEAE
V17	Saqui saqui	Bombacopsis quinata (Jacq.) Dugand.	BOMBACACEAE
V18	Sun sun	Didymopanax morototoni (Aubl.) Done et P.	ARALIACEAE
V19	Virola	Virola sebifera Aubl.	MYRISTICACEAE
V20	Zapatero	Peltogyne porphyrocardia Griseb.	CAESALPINIACEAE

failures, induced by growth stresses (brittleheart); in this case, it appears that only Tornillo from certain sites can be used for structural purposes.

Growth stresses that develop in the standing trees can sometimes cause problems during later processing - as dimensional instability during drying or as warping during sawing or as weaknesses due to minute compression failures - and in extreme cases, evidence of this can be seen during felling of the trees. If the tree trunk shatters or splits immediately upon felling, i.e., before drying, this may be a warning sign that the stem contains high growth stresses. It is possible to alleviate some of these stresses by means of careful kiln drying schedules, but it may be better simply to avoid species that show a preponderance of problems due to high growth stresses.

In spite of all of these problems, the sampled trees were harvested and the bucked logs were transported to the various subregional laboratories where the investigations described in the following chapters were carried out.

SPECIES IDENTIFICATION AND ANATOMY

The proper utilization of the timber species in a country may depend on being able to make dependable identification of the different species at various stages of processing - as standing trees, as sawlogs, and as lumber. For this reason, the development of techniques of species identification is a necessary part of a wood-utilization project. In the forest, this is usually the job of a botanist, who uses flowers, leaves, and bark as aids as well as general form and branching patterns as the tools for identification. Attention should also be paid to "folk" or vernacular methods of identification by the forest workers of a species if this is a species that has been cut previously.

At the sawmill the "folk" identification of the lumber from a particular species should be learned. However, this may be only of limited use in that the majority of sawmills will be handling very few species and, although a particular species can be distinguished from the others that pass through a particular mill, the identification techniques may not be too useful in distinguishing it from a much broader selection of species.

The final step is to carry out macro- and microexaminations of each species in a wood technology laboratory; this was done in the Project and it led to the publication by JUNAC of "Descripción General y Anatomica de 105 Maderas del Grupo Andino."[1] For each of the 20 or so species of each country, this manual contains four pages on each of the 20 species and includes the following information:

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[1] Information on the reports produced by JUNAC that are referred to in this publication is available from: PADT-REFORT, Junta del Acuerdo de Cartagena (JUNAC), Casilla de Correo 3237, Lima, Peru.

(a) Full size colour photographs of the transverse, tangential, and radial faces of a block of wood of that species;

(b) The scientific name, the family name, and its common names in each country of the subregion;

(c) The growth range of the species;

(d) The Holdridge life zones in which it grows;

(e) A description of the standing tree: crown, stem, and bark;

(f) A sensory description of the wood: colour, odour, taste, brightness, grain, texture, and striping or speckling;

(g) Probable uses;

(h) Macroscopic features: growth rings, vessel alignment, longitudinal parenchyma, rays;

(i) Three photomicrographs (transverse, tangential, radial) of 80 X magnification;

(j) Microscopic features: vessels, longitudinal parenchyma, rays, fibres, and extractives; and

(k) Bibliographic references.

One problem of wood utilization in tropical countries is that the same species may have a different common name in each country in which it appears and may even have different common names within a single country. Also, it is frequently very difficult to identify some species after the log has been sawn into lumber. It has been suggested that in tropical wood utilization precise species identification is not always necessary and that some measurable parameter (for example, density as estimated by Pilodyn penetration) will be an adequate indicator of the usefulness of the species for a particular purpose. In the case of density, it is known that both strength properties and natural durability are generally related to density and, therefore, grouping species together on the basis of density values will permit the assignment of an allowable stress and a durability rating to an unknown species without having to identify or test that species. However, this procedure is not sufficiently dependable to be safe enough for structural purposes.

In the traditional method of deriving allowable stresses from tests on small clear specimens, a very high correlation is obtained between most mechanical properties and density. This is true even at the fifth percentile level of the population of strength values, which is the level from which allowable stresses are derived. However, on tests of full-size structural members containing defects permitted in the grading rule, the fifth percentile value is much more weakly correlated with density; the behaviour at the fifth percentile (the "near-minimum" strength) is dominated by the effects of the defects present and, to a lesser extent, by the density. (For nonengineered construction, these strength considerations are of course not nearly as important as they are in engineered construction.) Similarly, there are too many exceptions to the general correlation of natural durability with density to permit one to use the relationship dependably.

In summary, although it can be extremely difficult in some cases to accurately identify the species of some particular lumber, it appears to be necessary to do so if the lumber is to be used in engineered construction or if dependence has to be placed upon its natural durability.

DRYING, PRESERVATION, AND WORKABILITY

When wood is used in the construction of houses, particularly in tropical countries, it is more likely to be considered successful if it dries well and if it can be readily treated with preservatives to provide durability against decay and insect attack. The 105 species of the Project were studied to learn their characteristics: (a) in air drying, (b) in kiln drying, (c) in a hot and cold soaking treatment with pentachlorophenol preservative, (d) in a vacuum-pressure treatment with pentachlorophenol preservative, and (e) in a vacuum-pressure treatment with CCA preservative.

This work was carried out in six laboratories in the five countries: Bolivia, Santa Cruz; Colombia, Bogota and Medellin; Ecuador, Quito; Peru, Lima; and Venezuela, Merida with the assistance of a subregional coordinator. The results of the work appear in a JUNAC publication "Secado y Preservación de 105 Maderas del Grupo Andino" and are summarized below.

Air Drying

The objectives of this work were to determine how long it took the wood of various species to dry from the green condition (i.e., at some moisture content (MC) greater than the fibre saturation point, which is around 25-30% MC) to an MC of 20%, and to note the type and extent of defects that developed as a result of shrinkage stresses induced by drying. With this information, it was possible to establish a set of standards for classifying the relative air-drying behaviour of a range of species.

Ten trees were sampled for each species, yielding a total of 1,050 trees (these were used for all of the drying and preservation studies). Two or three replications were taken from each tree. The actual drying specimens were 2.5 cm thick and 15 cm wide, with lengths of either 100, 120, or 150 cm in the various laboratories. The ends of the specimens were painted with aluminum paint to retard longitudinal moisture movement. Sample boards were used to monitor the progress of drying. The pieces were then open-piled above the ground to permit free air circulation around each piece and were covered to prevent direct exposure to sun and rain.

The researchers recorded the number of days it took for the wood to dry to an MC of 20%. Considerable variation was observed among the species and also among the various laboratories, this latter effect being due to the climate and to the particular experimental setup at that location. The location extremes were a low of 14 days average drying time in Medellin, Colombia, to a high of 149 days in Merida, Venezuela (where the wood was piled in a closed shed). So that the results from the different laboratories could be compared, a relative scale of drying rates was set up, as shown in Table 9, in an attempt to reduce the site-dependent influences on the test results. According to this scheme, the 105 species were assigned an air-drying rate classification of VF (very fast), F (fast), M (moderate), or S (slow) as noted in Table 10. (The species names can be found by reference to Tables 4-8.) Also shown in Table 10 is a wood-quality rating that indicates the extent of drying defects: A (no, or minor, drying defects), B (no more than 1% warping along any major dimension; length of end checks less than 5% of the length of the piece), and C (warping up to 3%; end checks up to 10% of the length of the piece). Of the 105 species, it was encouraging to find that 18 species had both a VF or F drying rate and an A drying quality.

Kiln Drying

In this portion of the study, the researchers wanted to see how long it took to kiln dry wood of the various species under three different kiln schedules, and to observe the kind and severity of defects that developed during drying. Again, with this information, it was possible to propose standards for classifying kiln-drying behaviour. Bolivia did not have the equipment to participate in this part of the work.

Table 9: Air Drying Time Categories (Days)

Drying rate	Santa Cruz, Bolivia	Bogota, Colombia	Medellin, Colombia	Quito, Ecuador	Lima, Peru	Merida, Venezuela
Very Fast (VF)	< 11	< 33	<6	<10	<30	<50
Fast (F)	11-22	33-70	6-12	10-20	31-53	50-105
Moderate (M)	23-44	71-140	13-25	21-42	54-110	106-210
Slow (S)	>44	>140	>25	>42	>110	>210

Table 10: Air Drying and Kiln Drying Performance

Species	Basic relative density	Air drying			Kiln drying		
		Drying time (days)	Rate[a]	Quality[b]	Schedule	Drying time (hours)	Quality
Bolivia							
B1	.51	36	M	B-A			
B2	.80	23	M	A-B			
B3	.50	22	F	B-A			
B4	.77	21	F	B			
B5	.62	31	M	A-B			
B6	.86						
B7	.74	22	F	A-B			
B8	.47	30	M	A-B			
B9	.52	26	M	A			
B10	.62	22	F	A			
B11	.42	21	F	A-B			
B12	.42	16	F	B-C			
B13	.51	24	M	B-A			
B14	.55	27	M	B-A			
B15	.49	37	M	B			

B16	.56	23	M	B-A			
B17	.40	26	M	A-B			
B18	.37	15	F	A			
B19	.65	19	F	B			
B20	.57	23	M	B-A			
Colombia							
C1 B	.46				Mi	229	A
C2 M	.82						
C3 M	.21	18	M	B-C	S	86	A-B
C4 M	.68	11	F	C	S	64	B-C
C5 M	.48				S	110	B-C
C6 M	.34	14	M	B	S	71	A-B
C7 M	.59	15	M	C	S	94	A
C8 B	.50	30	VF		S	40	A
C9 B	.69	60	F		Mi	206	A
C10 B	.68	90	M		Mo	182	A
C11 M	.34	17	M	B-C	S	82	A-B
C12 B	.32				S	51	A
C13 B	.43	120	M		Mi	306	A
C14 M	.31	19	M	B	S	86	A-B
C15 B	.58	18	VF				
C16 M	.46	11	F	B-C	Mi	149	B-C
C17 B	.63	105	M				
C18 B	.68	45	F				

Table 10 (con't)

Species	Basic relative density	Air drying			Kiln drying		
		Drying time (days)	Rate[a]	Quality[b]	Schedule	Drying time (hours)	Quality
Colombia (con't)							
C19 B	.62	60	F		Mi	258	A
C20 M	.45	10	F	B-C	S	86	B-C
C21 B	.37				Mo	89	A
C22 B	.42	24	VF		S	52	A
C23 B	.35				S	64	A
C24 B	.37				S	63	A
C25 B	.49	75	M		Mi	211	A
Ecuador							
E1	.74	33	M	B	S	56	B
E2	.66	33	M	B	Mo	72	B
E3	.62	15	F	B-C	S	42	B
E4	.55	45	S	B-C	Mo	95	B
E5	.53	30	M	B-C	S	50	B

Ecuador (con't)

E6	.76	120	S	B	Mi	250	B
E7	.36	18	F	B	S	66	B
E8	.36	36	M	B	S	64	B
E9	.59	31	M	B-C	Mo	68	B
E10	.71	47	S	B	S	66	B
E11	.54	15	F	B	Mo	54	B
E12	.43	14	F	B	S	84	B
E13	.39	20	F	B	S	50	B
E14	.51	14	F	B	S	72	B
E15	.44	45	S	B	S	56	B
E16	.57	27	M	B-C	S	46	B
E17	.40	31	M	B	S	53	B
E18	.37	15	F	B	S	60	B
E19	.33	29	M	B	S	63	B
E20	.61	26	M	B	S	88	B

Peru

P1	.65	60	M	C	Mi	60	C
P2	.59	40	F	A	S	55	A
P3	.53	65	M	A	S	45	A
P4	.41	62	M	A	S	45	A
P5	.70	53	F	A-B	Mo	70	B
P6	.60	47	F	A	S	45	A

Table 10 (con't)

Species	Basic relative density	Air drying			Kiln drying		
		Drying time (days)	Rate[a]	Quality[b]	Schedule	Drying time (hours)	Quality
Peru (con't)							
P7	.53	68	M	A	S	55	A-B
P8	.78	110	M	A-B	Mo	60	B
P9	.60	78	M	A-B	S	55	B
P10	.56	58	M	B-C	Mo	70	B
P11	.68	30	VF	B-C	Mo	60	B
P12	.30	37	F	A	S	55	A
P13	.36	38	F	A	S	45	A
P14	.41	51	F	A	Mo	70	C
P15	.71	76	M	A	Mo	60	B
P16	.72	87	M	B	S	45	A
P17	.48	37	F	A	S	45	A
P18	.67	60	M	B	Mo	60	B
P19	.44	45	F	A	S	55	A
P20	.38	38	F	A-B	Mo	60	B

Venezuela							
V1	.56	179	M	A-B	S	110	B
V2	.77	49	VF	A	S	110	B
V3	.54	114	M	A	S	110	B
V4	.50	82	F	A-B	S	110	B
V5	.55	150	M	B-C	Mo	120	B
V6	.55	550	S		Mi	150	B
V7	.65	114	M	A-B	Mo	120	B
V8	.66	114	M	A	S	110	B
V9	.64	123	M	A	S	110	B
V10	.35	131	M	B	Mo	120	B
V11	.78	114	M	B	S	110	B
V12	.47	202	M	A-B	S	110	A
V13	.65	123	M	A	S	110	A
V14	.78	141	M	A	S	110	B
V15	.49	70	F	A-B	Mo	150	A
V16	.57	62	F	A-B	Mi	120	B
V17	.39	425	S	A	S	110	A
V18	.36	73	F	B-C	S	110	A
V19	.37	43	VF	B-C	Mo	120	B
V20	.89	114	M	A	S	110	B

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[a] VF = very fast, F = fast, M = moderate, and S = slow.

[b] A = no, or minor, drying defects; B = no more than 1% warping along any major dimension (length of end checks less than 5% of the length of the piece); and C = warping up to 3% (end checks up to 10% of the length of the piece).

Three kiln schedules were used, severe (S), moderate (Mo), and mild (Mi); the steps in each of these schedules are listed in Table 11. They correspond approximately to certain kiln drying schedules for tropical hardwoods developed by the Princes Risborough Forest Products Laboratory in England, as follows: the Project schedule of S, Mo, and Mi corresponding to the Princes Risborough schedule of J, F, and between C and D. Table 10 shows, for each species, the kiln schedule used (or the most severe schedule reported), the drying time (in hours), and an indication of drying defects using the same quality scale as for air drying.

Wood Preservation

The wood preservation study was designed to determine, for three different preservative treatments, how the 105 species performed with regard to absorption and penetration of the preservative. On the basis of these results, a classification system for "permeability to preservatives" was established and the 105 species were rated accordingly.

The wood obtained was described earlier. The individual specimens were separated into heartwood and sapwood, and measured 5 x 5 cm in section x 50 cm long. They were first air-dried to 25% MC, coated with aluminum paint, and then weighed.

Three treatments were used: (a) a hot-cold bath in a 5% solution of pentachlorophenol in oil, (b) a vacuum-pressure treatment in a 5% solution of pentachlorophenol in oil, and (c) a vacuum-pressure treatment in a 4% solution of CCA preservative in water. Treatment (a) lasted 24 hours, comprising 5 hours at 70°C followed by cooling to ambient temperature for 19 hours. In treatments (b) and (c), an initial vacuum of 500 mm Hg was drawn for 30 minutes, followed by a pressure of 14 kg/cm^2 for 120 minutes, followed (optionally) by a vacuum of 500 mm Hg for 30 minutes. The specimens were weighed again to ascertain the weight of liquid absorbed, and classified as follows: HA (high absorption), more than 150 kg/m^3; GA (good absorption), 100-150 kg/m^3; PA (poor absorption), 50-99 kg/m^3; and NA (no absorption), less than 50 kg/m^3.

Table 11: Kiln Drying Schedules

Wood MC[a] (%)	Severe (S)			Moderate (Mo)			Mild (Mi)		
	Dry bulb (°C)	Wet bulb (°C)	RH[b] (%)	Dry bulb (°C)	Wet bulb (°C)	RH (%)	Dry bulb (°C)	Wet bulb (°C)	RH (%)
Green	60	56	80	50	47	80	40	37	80
60	65	58	70	55	49	70	-	-	-
50	70	60	60	-	-	-	-	-	-
40	75	61	50	60	51	60	40	35	70
30	80	62	40	65	52	50	45	37	60
25	-	-	-	70	54	40	50	40	50
20	80	60	35	70	50	35	55	42	40
15	-	-	-	-	-	-	55	37	30

[a] MC = moisture content.
[b] RH = relative humidity.

The penetration of preservative into the wood was determined by cutting through the specimens, applying a colour reagent to the cut surface, and classifying the penetration as: TP (total penetration), all the transverse section was penetrated; PP (peripheral penetration), a more or less uniform ring of penetration around the section; IP (irregular penetration), the ring of penetration was not well defined; and NP (no penetration), insignificant penetration.

The absorption and penetration results were combined to yield an overall "permeability to preservatives" rating: P (permeable), HA plus TP; MP (moderately permeable), GA plus TP or PP; SP (slightly permeable), PA plus IP; and I (impermeable), NA plus NP. These ratings for the heartwood and sapwood of the Project species are listed in Table 12.

Before ending this chapter, here are a few last comments on drying and preservation.

- The relationship between preservative absorption and basic relative density was explored by calculating linear regressions. In all cases, absorption decreased as density increased. There was no difference in behaviour between heartwood and sapwood, but there was a difference related to the type of treatment. The highest correlation coefficient $r = 0.6$ was obtained for the vacuum-pressure treatment with pentachlorophenol; the other treatments yielded r-values between 0.3 and 0.4.

- It is essential to have seasoned lumber for most purposes in building construction because it avoids green lumber's potential problems with decay, stain, insect attack, connector corrosion, warping, loosening of joints and checking in service. However, with some of the higher density woods, it is difficult to drive nails into them when dry; as a result, many builders actually prefer to work with lumber in the green condition.

- Various methods are available for drying lumber: air drying, kiln drying, chemical seasoning, and all of these are well described in the literature. However, there is one technique that should

Table 12: Permeability to Preservatives[a]

Species	Basic relative density	Hot-cold bath with penta		Vacuum-pressure with penta		Vacuum-pressure with CCA	
		Sapwood	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood
Bolivia							
B1	.51		P				P
B2	.80		I				SP
B3	.50		P				P
B4	.77		MP				P
B5	.62		MP				MP
B6	.86		I				SP
B7	.74		SP				MP
B8	.47		MP				P
B9	.52		P				P
B10	.62		I				MP
B11	.42		SP				MP
B12	.42		MP				P
B13	.51		MP				MP
B14	.55		I				SP
B15	.49		SP				MP
B16	.56		P				P

Table 12 (con't)

Species	Basic relative density	Hot-cold bath with penta		Vacuum-pressure with penta		Vacuum-pressure with CCA	
		Sapwood	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood
Bolivia (con't)							
B17	.40		P				MP
B18	.37		P				P
B19	.65		MP				P
B20	.57		P				P
Colombia							
C1 B	.46	MP	SP	MP	MP	P	MP
C2 M	.82		SP		SP		SP
C3 M	.21		MP		P		P
C4 M	.68		I		MP		MP
C5 M	.48		P		MP		MP
C6 M	.34		MP		MP		MP
C7 M	.59		P		P		P
C8 B	.50	P	P	P	P	P	P
C9 B	.69	MP	SP	MP	SP	P	P

C10 B	.68	SP	SP	SP	SP	P	P
C11 M	.34		MP		P		P
C12 B	.32	P	P	P	P	P	MP
C13 B	.43	SP	I	P	SP	MP	MP
C14 M	.31		P		P		P
C15 B	.58		I	SP	SP	MP	SP
C16 M	.46		SP		SP		MP
C17 B	.63	SP	I	MP	I	MP	MP
C18 B	.68	MP	SP	SP	MP	P	P
C19 B	.62	MP	MP	MP	MP	P	MP
C20 M	.45		MP		P		P
C21 B	.37	P	P	P	P	P	P
C22 B	.42	P	P	P	P	MP	MP
C23 B	.35	P	MP	P	P	P	MP
C24 B	.37	SP	MP	P	MP	P	P
C25 B	.49	I	SP	MP	SP	P	SP
Ecuador							
E1	.74	MP	SP	MP	MP	MP	MP
E2	.66	MP	MP	MP	SP	MP	MP
E3	.62	P	P	P	MP	P	P
E4	.55	I	I	I	I	MP	I
E5	.53	SP	I	MP	MP	MP	SP
E6	.76	I	I	I	I	I	I
E7	.36	MP	SP	MP	MP	MP	MP

Table 12 (con't)

Species	Basic relative density	Hot-cold bath with penta		Vacuum-pressure with penta		Vacuum-pressure with CCA	
		Sapwood	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood
Ecuador (con't)							
E8	.36	MP	MP	MP	MP	P	P
E9	.59	MP	MP	MP	MP	MP	MP
E10	.71	I	I	I	I	SP	I
E11	.54	MP	MP	MP	MP	P	MP
E12	.43	SP	SP	MP	MP	MP	MP
E13	.39	P	P	P	P	P	P
E14	.51	SP	I	MP	SP	MP	MP
E15	.44	P	P	P	P	P	P
E16	.57	P	P	P	P	P	P
E17	.40	P	P	P	P	P	P
E18	.37	SP	I	MP	MP	MP	MP
E19	.33	SP	SP	MP	MP	MP	MP
E20	.61	MP	SP	P	MP	MP	MP

Peru

P1	.65	I	I	SP	I
P2	.59	P	P	P	P
P3	.53	SP	I	MP	SP
P4	.41	SP	I	P	MP
P5	.70	P	MP	P	P
P6	.60	MP	SP	P	SP
P7	.53	P	MP	P	P
P8	.78	I	I	I	I
P9	.60	SP	I	MP	MP
P10	.56	MP	MP	P	P
P11	.68	P	P	P	P
P12	.30	P	P	P	P
P13	.36	P	P	P	P
P14	.41	SP	I	SP	SP
P15	.71	P	MP	P	P
P16	.72	SP	I	MP	MP
P17	.48	P	P	P	P
P18	.67	MP	MP	P	P
P19	.44	SP	I	MP	MP
P20	.38	SP	SP	MP	MP

Table 12 (con't)

Species	Basic relative density	Hot-cold bath with penta		Vacuum-pressure with penta		Vacuum-pressure with CCA	
		Sapwood	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood
Venezuela							
V1	.56	P	I	P	I	P	I
V2	.77	P	I	P	I	P	I
V3	.54	MP	MP	P	P	P	P
V4	.50	P	SP	P	SP	P	MP
V5	.55	SP	I	MP	SP	P	SP
V6	.55	P	MP	P	MP	P	P
V7	.65	P	MP	P	P	P	P
V8	.66	MP	I	P	SP	P	I
V9	.64	MP	SP	P	P	P	P

V10	.35	P	I	P	I	P	I
V11	.78	I	I	MP	I	P	I
V12	.47	P	SP	P	P	P	P
V13	.65	SP	I	MP	SP	P	I
V14	.78	MP	I	MP	SP	P	SP
V15	.49	MP	I	P	MP	P	I
V16	.57	MP	MP	P	P	P	P
V17	.39	P	I	P	I	P	I
V18	.36	P	MP	P	P	P	P
V19	.37	P	P	P	P	P	P
V20	.89	SP	I	SP	I	MP	I

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[a]P = permeable, MP = moderately permeable, SP = slightly permeable, and I = impermeable.

possibly be given more attention: solar drying, i.e., using solar energy to provide the heat and power to operate a kiln-like process. This is one aspect of the general philosophy of trying to find the most appropriate technology for a given situation rather than simply adopting a North American or European solution, which may be capital- or energy-intensive.

Some species are naturally resistant to termite attack, e.g., Palo Maria and Lagarto. However, it has been observed that termites may build their tunnels along such resistant wood (without attacking it) to gain access to wood of a less durable species, even though it is located well above the ground.

From the point of view of housing, the paramount considerations for a preservation process seem to be economy, good resistance to leaching, and low toxicity to humans and animals. One important point is that pressure impregnation techniques usually involve expensive physical plant setups. The more appropriate technology here may be the use of diffusion treatments, and the investigation of their use is recommended.

An additional recommendation that can be offered here is that we could try to learn more from the successful historical and folk use of wood around the world. Burdened with the arrogance of modern technology, we often fail to take advantage of indigenous knowledge about organic materials that has built up over the centuries but has never been published. For example, the authors have been told that a tribe of Indians in the Guyana region of Venezuela rub a garlic-like substance in a kerosene solvent on the poles of their shelters to repel termites. Now, it is not suggested that we should start rubbing garlic on our houses, but the example is offered as an apparently successful method of protection that has not reached the literature. Thus, a study could be carried out of traditional methods of wood construction to see what lessons for the future could be learned.

Workability

JUNAC has produced a research report entitled "Características de Trabajabilidad de 105 Maderas del Grupo Andino" (Workability Characteristics of 105 Woods of the Andean Group) to which major contributions were made by Luc Ninin and Octavio Lopez. It comprises two volumes: one contains detailed data and the other presents summarized data. The format is modular: each machining property is completely dealt with in its own section - introduction, methods, materials, results, analysis, conclusions, and recommendations. This feature will make it easy for wood users to locate and extract just the information they are particularly interested in. The report deals with five aspects of workability or machinability: drilling, turning (on a lathe), sanding, planning, and shaping (for moldings).

The 105 species are classified as to how well they perform in these various operations. Also given are recommendations, based on test results, as to the optimum industrial parameters for each operation, e.g., feed speed, knife angle, turning speed, influence of grain direction.

PHYSICAL AND MECHANICAL PROPERTIES OF SMALL CLEAR SPECIMENS

Scope

In determining the mechanical properties of the Andean species two quite different, but complementary, approaches were taken: the traditional one of testing small defect-free specimens (small clear method) and the one more currently used of testing full-size members that contain grade-permitted defects (in-grade method).

The results of the small clear specimen tests are presented in this chapter; in-grade test results appear in the following chapter. The small clear results formed the initial basis both for the establishment of species groups and for the derivation of allowable stresses, whereas the in-grade results were used to confirm the allocation of species to species groups, to improve the efficacy of the Grading Rule, and to verify the allowable stresses.

Small Clear Specimen Tests

Ten trees were obtained for each of 104 species, and two samples were taken from each tree. The individual test specimens were machined from the samples, and either kept in the green condition or allowed to air dry to approximately 12-14% MC. The individual tests that were carried out comprised the following: (a) moisture content, (b) density, (c) shrinkage (radial, tangential, and volumetric), (d) static bending (stress at proportional limit, modulus of rupture, and modulus of elasticity), (e) compression parallel to grain (maximum crushing stress), (f) compression perpendicular to grain (stress at proportional limit), (g) shear (radial and tangential), (h) hardness (side and end), and (i) toughness (radial and tangential).

The results of all of these tests are tabulated in a series of five JUNAC reports, one for each country, entitled:

- Tablas de Propiedades Físicas y Mecánicas de la Madera de 20 Espécies de Bolívia
- Tablas de Propiedades Físicas y Mecánicas de la Madera de 24 Espécies de Colombia
- Tablas de Propiedades Físicas y Mecánicas de la Madera de 20 Espécies del Ecuador
- Tablas de Propiedades Físicas y Mecánicas de la Madera de 20 Espécies del Peru
- Tablas de Propiedades Físicas y Mecánicas de la Madera de 20 Espécies de Venezuela.

A variety of standards were used throughout the subregion for the selection, sampling, conditioning, and testing of the wood (eg., COPANT, ITINTEC, and ASTM Standards) but these are basically similar to the procedures of Standard D143 of the American Society for Testing and Materials, which has become the norm for small clear specimen testing in North America.

For each property, the statistics given in the tables in the JUNAC reports include: the mean value, the coefficient of variation, the number of specimens tested, and the number of trees sampled. The "mean" results for each physical and mechanical property of the 104 species are reproduced in Appendices A and B of this publication. The "Seco 12" results were obtained by adjusting the air dry results from their actual MC values to an MC of 12%.

Mechanical properties, particularly those of small clear specimens, are influenced by wood density. Therefore, regression analyses were conducted to determine the influence on modulus of rupture (MOR) and modulus of elasticity (MOE) of basic relative density (DB). For the 104 species, the linear regressions are:

MOR (kg/cm2) = -109 + 1480 DB (r2 = 0.83)
MOE (103 kg/cm2) = 8.01 + 177.5 DB (r2 = 0.69)

There was also a good correlation between MOR and MOE; if this correlation also holds for full-size in-grade lumber, the use of mechanical stress rating for tropical hardwoods is probably feasible.

Species Groups

It would not be practical to assign a separate set of allowable stresses to each of the 104 species for which small clear mechanical properties were determined. Instead, it was decided to allocate the species to three species groups. Because of the good correlation between bending strength and density, density was used as the criterion for the initial assignment of species to the groups: group A: basic density = 0.71 to 0.90, group B: basic density = 0.56 to 0.70, and group C: basic density = 0.40 to 0.55. The strongest and stiffest species are in group A, those of moderate properties in group B, and those of least strength and stiffness in group C.

As explained later, it is prudent not to depend solely on small clear specimen test results for structural purposes, and, thus, full-size, in-grade beam tests were conducted for about half of the 104 species. The species chosen for these latter tests were the ones that appeared to be most promising for structural purposes. The final choices as to which groups the individual species were allocated to were then made on the basis of the two types of tests. The resulting species groups, comprising 51 of the original 104 species, are shown in Table 13.

In the future, it will be desirable to incorporate many additional species into these groups. Harry Booth (1981) has proposed a methodology for doing this. The basic idea is to make use of the correlations between density and the mechanical properties of small clear specimens, and to carry out tests on full-size in-grade members only when a species is on the border between two groups. The steps in his methodology are as follows:

(a) Determine the basic density (oven-dry weight divided by green volume) from a quartered pith-free disc about 8-cm thick cut from the top of the first log

Table 13: Species Groups of Structural Timber

Country	Group	Common name
BOLIVIA	A	Almendrillo
		Curupau
	B	Coquino
		Murure
		Verdolago
	C	Palo maria
		Yesquero
COLOMBIA	A	Chanul
		Chaquiro
		Oloroso
	B	Machare
		Nato
		Pantano
	C	Aceite mario
		Carra
		Dormilon
		Mora
		Sande
		Tangare
ECUADOR	A	Caimitillo
		Guayacan pechiche
	B	Chanul
		Moral fino
		Pituca
	C	Fernansanchez
		Mascarey
		Sande
PERU	A	Estoraque
		Palo sangre negro
		Pumaquiro

(cont'd)

	B	Huayruro
		Manchinga
	C	Catahua amarilla[a]
		Copaiba
		Diablo fuerte
		Marupa[a]
		Tornillo
VENEZUELA	A	Algarrobo
		Mora
		Perhuetamo
		Zapatero
	B	Aceite cabimo
		Apamate
		Charo amarillo
		Chupon rosado
		Guayabon
		Pardillo amarillo
	C	Carne asada
		Mureillo
		Saman
		Saqui saqui

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[a] To be moved to a future group D.

of the merchantable bole of the tree. As many trees as possible over the geographic range of the species should be sampled, and the details of the sites sampled should be recorded in case different zones should yield statistically significantly different results.

(b) If both the mean and the lower 5% exclusion value of the density range of a species lie within the limits of a particular group, the species can be allocated to that group without further calculations or testing.

(c) Otherwise, for species of importance that lie close to the boundaries of a group, a minimum of 50 beams can be either nondestructively E-rated flatwise or proof loaded to a stress level about twice the estimated fifth percentile modulus of rupture value.

(d) If the fifth percentile values of the modulus of elasticity and of the modulus of rupture are above the minima stipulated for a particular group, the species can be assigned to that group. Otherwise, it will go into the next lower group.

Derivation of Allowable Stresses

All species within a particular group are assigned the same allowable stresses and these values are governed by the weakest species in that group.

The traditional method of deriving allowable stresses for stress-graded lumber of a particular species is to test small, clear specimens in the green condition and then to modify these results by multiplying by a series of modification factors representing the variability of the data, the effect of duration of load, the effect of moisture content, the effect of beam depth, the weakening effect of defects that are permitted in a particular grade, and by dividing by the desired factor of safety.

This traditional approach has been challenged by work on temperate conifers by Madsen (1975). His research results lead him to question the following steps in the allowable stress derivation process:

(a) The determination of the lower 5% exclusion limit value based on an assumed Gaussian distribution of strength values; this appears to be the actual distribution for small clear specimens of wood but is not the distribution of populations of in-grade lumber;

(b) The effect of duration of load at the 5% exclusion limit; again, in his tests, there is no effect in many cases;

(c) The effect of moisture content changes at the lower 5% exclusion limit; again, in his tests, there is no effect in many cases;

(d) The reliability of grading rules in predicting strength at the lower 5% exclusion limit; he found that the rules were reliable for distinguishing the strongest and the weakest grades, but not the intermediate

Table 14: Test Results in Species Groups A, B, and C

			Static bending								Compression					
			MOR^a				MOE^b									
			Small clear specimens		Beams		Small clear specimens		Beams		Parallel to grain		Perp. to grain		Shear	
Species	Country^c	Specific gravity	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N
Group A																
Zapetero	V	0.89	1221	967	1044	641	169	139	173	146	684	452	129	106	164	103
Curupau	B	0.86	1175	1036	727	462	149	127	150	119	564	454	157	124	155	107
Almendrillo	B	0.80	1092	703	841	547	141	101	159	127	628	324	153	119	146	108
Mora	V	0.78	1103	868	1072	828	158	96	200	166	528	379	67	46	129	93
Perhuetamo	V	0.78	877	807	913	688	123	89	156	136	578	538	77	68	126	91
Algarrobo	V	0.77	1069	681	877	610	138	103	157	108	391	307	80	39	146	86
Guayacan pechiche	E	0.76	900	780	740	516	132	104	193	150	441	373	99	54	94	67
Caimitillo	E	0.74	1005	827	786	608	175	135	203	160	459	417	68	48	89	-
Chanul	C	0.69	861	658	789	466	141	98	177	133	471	335	78	62	103	79
Chaquiro	C	0.68	1011	708	918	605	137	110	197	149	512	433	110	94	104	83
Oloroso	C	0.68	986	912	706	441	148	124	168	113	371	270	96	86	97	73
Pumaquiro	P	0.67	955	838	751	502	148	148	133	103	522	426	96	65	118	67

Group B																
Moral fino	E	0.71	1074	787	658	394	124	90	150	112	542	352	104	60	112	63
Chupon rosado	V	0.66	733	588	701	567	119	95	128	105	346	180	58	43	103	82
Chanul	E	0.66	963	738	709	472	143	109	156	124	428	326	60	44	88	62
Pardillo amarillo	V	0.65	804	603	731	473	137	91	130	98	425	357	67	53	111	91
Charo amarillo	V	0.65	786	617	680	452	105	81	129	97	448	296	68	56	114	53
Verdolago	R	0.65	848	687	648	442	104	84	133	104	393	299	90	71	100	65
Guayabon	V	0.64	771	447	788	442	113	71	123	93	437	342	65	48	106	-
Nato	C	0.63	820	483	617	438	124	77	136	82	383	218	92	71	91	60
Pantano	C	0.62	819	571	715	462	112	90	157	98	391	348	86	55	86	53
Coquino	R	0.62	739	520	731	397	90	51	123	108	349	246	78	60	97	63
Murure	R	0.62	940	764	724	328	117	88	140	119	497	314	98	77	100	51
Machare	C	0.58	1023	701	690	429	141	106	167	131	495	368	80	55	84	60
Aceite cabimo	V	0.56	802	485	614	463	116	73	117	95	360	246	44	33	82	52
Apamate	V	0.54	837	662	764	576	125	93	121	105	385	307	42	29	88	69
Pituca	E	0.51	854	645	641	510	106	75	146	128	428	268	83	53	94	63
Group C																
Copaiba	P	0.60	731	502	736	469	110	54	112	92	359	281	72	44	100	70
Mascarey	E	0.59	723	497	517	364	113	76	139	76	309	202	41	23	71	48
Yesquero	R	0.57	720	441	521	300	83	59	99	65	349	249	79	56	93	62
Carne asada	V	0.55	600	436	603	517	106	76	113	90	293	239	34	22	75	56
Palo maria	R	0.55	683	370	509	330	92	76	125	116	343	257	60	47	90	58
Fernan sanchez	E	0.53	719	297	550	420	111	47	143	97	334	223	58	25	92	59
Diablo fuerte	P	0.53	608	431	505	360	99	70	106	87	302	256	57	44	89	63

Table 14 (con't)

			Static bending								Compression					
			MOR[a]				MOE[b]									
			Small clear specimens		Beams		Small clear specimens		Beams		Parallel to grain		Perp. to grain		Shear	
Species	Country[c]	Specific gravity	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N	$\bar{X}$	0.05N
Group C (con't)																
Carra	C	0.50	773	554	619	295	117	102	160	124	350	199	50	36	84	44
Tangare	C	0.49	631	528	580	348	92	63	142	115	341	260	49	35	68	44
Saman	V	0.49	701	408	472	362	92	57	86	75	271	159	39	31	91	61
Mureillo	V	0.47	644	506	557	408	121	101	118	104	254	179	32	23	64	42
Aceite mario	C	0.46	652	461	659	295	114	82	153	104	303	258	42	31	67	42
Mora	C	0.46	715	541	365	240	93	58	117	81	357	251	54	57	83	-
Tornillo	P	0.44	579	465	380	302	109	87	87	67	287	175	57	43	82	57
Dormilon	C	0.43	655	474	477	255	96	69	133	97	335	214	67	59	74	58
Sande	C	0.42	587	474	508	375	103	75	129	111	298	198	39	27	57	38
Sande	E	0.40	505	334	486	319	86	61	129	100	247	182	26	17	55	33
Saqui saqui	V	0.39	650	485	459	281	96	73	90	73	271	176	30	12	59	44

[a] MOR = modulus of rupture.
[b] MOE = modulus of elasticity.
[c] B = Bolivia, C = Colombia, E = Ecuador, P = Peru, and V = Venezuela.

Table 15: Allowable Stress Derivation Factors

Factor	Bending	Shear	Compression parallel	Compression perpendicular
Quality	0.80	-	-	-
Size	0.90	-	-	-
Duration of load	1.15	-	1.25	-
Safety	2.00	4.00	1.60	1.60

Table 16: Allowable Stresses (kg/cm^2)

Group	Bending	Tension	Compression parallel	Compression perpendicular	Shear	$MOE_{0.05}$	MOE_{mean}
A	210	145	145	40	15	95000	130000
B	150	105	110	28	12	75000	100000
C	100	75	80	15	8	55000	90000

ones. Accordingly, some consolidation and simplification of the current North American grading rules may be in order.

The Project researchers decided to use the traditional method but, because of Madsen's findings, full-size, in-grade specimens were tested as well as small clear specimens to serve as a check.

Numerically, the derivation of allowable stresses consisted of determining the fifth percentile values of the distributions of small clear specimen results, multiplying by a quality factor for beams that represents the ratio of full-size in-grade beam MOR values to small clear MOR values, multiplying by a size effect factor for bending members, dividing by a duration of load factor, and dividing by a safety factor. The fifth percentile strengths (0.05N) are in Table 14. The values of the factors are in Table 15 and the resulting allowable stresses are listed in Table 16. In summary: allowable stress = (0.05N) x Quality factor x size effect factor/duration of load factor x safety factor.

Two modulus of elasticity values are shown. The average value, MOE_{mean}, is used for estimating the deflections of structural members. $MOE_{0.05}$ is the fifth percentile modulus of elasticity value; it is used for those cases where MOE is involved in the strength of the member, eg., the buckling capacity of slender columns or the onset of lateral instability of deep beams.

STRENGTH AND STIFFNESS OF FULL-SIZE, IN-GRADE BENDING MEMBERS

In-Grade Testing and the Grading Rule

In the first phase of the Project, full-size, in-grade bending tests were carried out on 46 of the 104 species sampled. These tests were conducted to confirm the placement of species in species groups and to verify that the allowable stresses assigned to the groups were appropriate. The mean and fifth percentile values of the beam results are listed under the heading "Beams" in Table 14.

Another purpose of the testing was to provide preliminary information on the relationships between the strength properties of beams and the defects that can occur in commercially produced lumber. Wood, when it comes from the saw as lumber, can contain a wide range of defects, both natural and man-made. Each of these defects will have some influence on how acceptable the wood is to the purchaser and on how the wood will be used. Some defects effect only the appearance and aesthetic qualities of the piece, while others can seriously reduce its strength. It is this latter category of defects that is of greatest concern in the structural utilization of wood products. To control the impact of these defects on manufactured wood products, various classification systems can be devised. To each class (or grade) of wood is assigned a set of rules that will prescribe the worst defects permitted in that grade: the types of defects, their size, extent, frequency, and location. The objective of these prescriptions is to gain the assurance that the strength of almost all the pieces within a certain grade will not fall below a certain level. This minimum strength can then be divided by a factor of safety to arrive at an allowable stress for that grade. Thus, this kind of grading is called stress grading. Furthermore, because it depends on visual (rather than mechanical) techniques, it is called visual stress grading.

The in-grade test results of the first phase of the Project, therefore, provided the information to produce early drafts of JUNAC's Visual Stress Grading Rule for Structural Lumber (La Regla de Clasificación Visual para Madera Estructural). Verification and fine-tuning of this Grading Rule were needed; a major study to do this was carried out in the second phase of the Project as described in the next section.

Effect of Defects on the Stiffness and Strength of Beams of Five Species of the Andean Subregion

The title of this section is a translation of the title of a JUNAC research report by Dr Hugo Scaletti "Influencia de Defectos en la Rigidez y Resistencia de Vigas de 5 Espécies de la Subregion Andina" on work that he led at the Andean Wood Engineering Laboratory (El Laboratorio Andino de Ingenieria de la Madera, or LADIMA) in Lima.

A total of 526 full-size, in-grade beams (4 cm x 14 cm x 3.00 m span) were tested in static bending under third-point loading. For each beam, Scaletti's team recorded the bending strength (modulus of rupture or MOR), the bending stiffness (modulus of elasticity or MOE), the mode of failure, and all visible defects and wood characteristics. Five species were studied; they all grow throughout the subregion and include almost the full range of wood densities and defects found there. In some cases, the tests were carried out in both the green and air-dry conditions; in other cases, only the air-dry condition was used (Table 17).

The objective of this work was to determine the relationships between wood defects and beam properties (MOR and MOE). There were two spin-off objectives: (a) to revise the earlier drafts of the Grading Rule in the light of the test results so that it would dependably reject beams having low MOR and MOE values, and (b) having made the grades dependable indicators of MOR and MOE, to determine whether the allowable bending stresses for the various species groups should be changed.

Table 17: Testing of Full-Size, In-Grade Beams Under Green and Air-Dry Conditions

Species[a]	Basic relative density	No. of beams tested[b]	
		Green	Air-dry
Marupa	0.35	35	73
Catahua Amarilla	0.40	62	72
Tornillo	0.50	56	55
Manchinga	0.68	-	106
Estoraque	0.78	-	67
Total		153	373

[a] Common name used in Peru.
[b] Total beams tested = 526.

Small clear bending specimens 2.5 cm x 2.5 cm x 41 cm were cut from each of the tested full-size beams. In most cases, two small specimens were obtained and their results were averaged; in a few situations it was possible to obtain only one (or sometimes zero) specimens from the beam. The small specimens were tested in accordance with the provisions of ASTM Standard D143 for secondary static bending specimens. The ratio R_R of each beam MOR to its corresponding small specimen MOR was calculated, and this number was called the "quality factor." The ratios R_E of corresponding MOEs were also calculated.

Each beam was graded in accordance with the version of the Grading Rule then in effect. (The most current Grading Rule provisions are listed in Table 18; they do not differ greatly from the rules used to grade the tested beams.) Under those rules, of the 526 beams tested, 182 were acceptable and 344 were rejected. A summary of the "average" results of this study is in Table 19; of perhaps even greater interest are the "minimum" test results that also appear in Table 19. Abbreviations and units used in the table are as follows: G, green condition; D, air-dry condition; MOR, modulus of rupture (kg/cm^2); MOE, modulus of

Table 18: Andean Pact Visual Grading Rule for Structural Timber

	Defects	Figure	Tolerances
1.	Brittleheart	-	Not permitted.
2.	Checks	-	Permitted if the distribution is moderate; depth must not exceed 1/4 of the thickness of the piece.
3.	Compression failures	10	Not permitted.
4.	Decay	11	Not permitted.
5.	End splits	12	Permitted only at one end of the piece and only to a length not exceeding the width of the face of the piece.
6.	Insect holes - large	-	Permitted when their distribution is moderate and superficial; not more than 3 holes in 100 cm; must not be aligned or pass through the piece.
	- small	13	Permitted when their distribution is moderate and covers an area not greater than 1/4 of the length of the piece; not more than 6 holes in 100 cm^2; must not be aligned or pass through the piece.
7.	Knots - knot clusters	-	Not permitted.

(con't)

	- loose knots	-	Maximum diameter permitted is the lesser of 2 cm and 1/8 of the width of the face of the piece.
	- tight knots	9	Maximum diameter permitted is the lesser of 4 cm and 1/4 of the width of the face of the piece.
8.	Pith	14	Not permitted.
9.	Shake	-	Permitted if it is superficial, parallel to the axis of the piece, and not longer than 1/4 of the length of the piece; not permitted on the corners of the piece.
10.	Sloping grain	-	Not greater than 1:8 in any part of the piece.
11.	Stain	-	Permitted only if it is certain that the colour change is not due to decay.
12.	Wane	-	On one corner only, extending not more than 1/4 of the width nor more than 1/4 of the thickness of the piece.
13.	Warp - cup	-	Not more than 1.0% of the width of the piece.
	- bow	-	Not more than 0.3% of the length of the piece.

(con't)

	- crook	-	Not more than 0.3% of the length of the piece.
	- twist	-	Not more than 0.3% of the length of the piece.
14.	Wide bands of Parenchyma	-	Not permitted in members subject to compression stress.

elasticity (10^3 kg/cm^2); A, accepted by the Grading Rule; R, rejected by the Grading Rule; N, number of beams; R_R, ratio of MOR (beams)/MOR (small specimens); and R_E, ratio of MOE (beams)/MOE (small specimens.

The test results indicated the following:

(a) Higher density species were stronger and stiffer than lower density species.

(b) Beams tested in the air-dry condition were stronger and stiffer, on the average, than beams tested in the green condition. With respect to strength, the difference between the populations diminished at the lower ends of the population distributions.

(c) For beams tested green, most of the failures initiated in the maximum compression zone of the beam. In contrast, most failures in the air-dry beams started in the maximum tension zone.

(d) The relationship between defects and strength was more evident in the air-dry beams, i.e., both the mean and the minimum quality factors R_R were lower for air-dry beams than for green beams. These beams also failed more abruptly and noisily than green beams.

(e) In virtually all cases, the quality factor R_R was less than unity, i.e., the beam MOR was less than the small specimen MOR. The overall average quality factor for beams accepted by the Grading Rule was 0.74 and the minimum value was 0.43. The minimum value

Table 19: Mean and Minimum Test Results[a]

Species:	Marupa		Catahua		Tornillo		Manchinga	Estoraque	Average
Condition:	G	D	G	D	G	D	D	D	
Mean									
MOR									
A	402	469	445	492	436	573	775	1089	
R	244	277	317	381	413	495	613	863	
All	289	340	381	410	426	528	653	944	
MOE									
A	88	96	82	83	94	114	149	281	
R	69	83	68	79	92	108	133	179	
All	74	87	75	80	93	110	135	187	
R_R									
A	0.93	0.74	0.85	0.70	0.68	0.74	0.74	0.66	0.74
R	0.62	0.39	0.72	0.56	0.68	0.62	0.61	0.55	0.60
All	0.72	0.57	0.79	0.60	0.68	0.65	0.64	0.59	0.65

Table 19 (con't)

Species:	Marupa		Catahua		Tornillo		Manchinga	Estoraque	Average
Condition:	G	D	G	D	G	D	D	D	
Mean (con't)									
R_E									
A	1.00	1.00	1.06	0.94	0.91	1.00	1.06	1.12	1.01
R	0.92	0.89	0.94	0.86	0.89	1.00	1.02	1.03	0.96
All	0.95	0.93	1.00	0.88	0.90	1.00	1.03	1.06	0.98
N									
A	10	24	31	19	32	16	26	24	
R	25	49	31	53	24	39	80	43	
All	35	73	62	72	56	55	106	67	
Minimum									
MOR									
A	349	385	331	367	325	430	584	1024	
R	76	115	78	60	126	178	259	150	

MOE								
A	69	81	60	59	65	84	118	158	
R	38	63	28	45	64	75	85	81	
R_R									
A	0.80	0.67	0.62	0.59	0.54	0.61	0.61	0.43	0.43
R	0.20	0.19	0.18	0.06	0.23	0.21	0.27	0.09	0.06
R_E									
A	0.34	0.88	0.74	0.66	0.58	0.81	0.92	0.89	0.57
R	0.56	0.71	0.38	0.42	0.58	0.73	0.73	0.49	0.38
N									
A	10	24	31	19	32	16	26	24	
R	25	49	31	53	24	39	80	43	
All	35	73	62	72	56	55	106	67	

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[a] Abbreviations and units used are as follows: G = green condition, D = air dry condition, MOR = modulus of rupture (kg/cm^2), MOE = modulus of elasticity (10^3 kg/cm^2), A = accepted by the Grading Rule, R = rejected by the Grading Rule, N = number of beams, R_R = ratio of MOR (beams)/MOR (small specimens), and R_E = ratio of MOE (beams)/MOE (small specimens).

subsequently increased to 0.50 with later modifications to the Grading Rule. For beams rejected by the Grading Rule, the quality factor was as low as 0.06. These findings indicate that the Grading Rule is effective in eliminating weak beams, which is highly desirable; however, it is unfortunate that some relatively good material is also being rejected, as indicated by the fact that the mean quality factor for rejected beams is 0.60. This is due, in part, to the defect that caused the rejection being located in a low-stressed zone of the beam. However, the Grading Rule applies to all types of structural members - not just beams - and, thus, high-quality factors might not be achievable under other stress modes, e.g., reverse bending or axial tension.

(f) The effect of defects on MOE values was much less than on MOR values. There was virtually no difference between the average beam MOEs and the small specimen MOEs; the average ratio R_E was only 5% less for rejected beams than for accepted beams. However, the minimum values show a greater spread: R_E for accepted beams was 0.57, and for rejected beams it was 0.38. Therefore, it appears that, although the Grading Rule is not very effective in separating high MOE beams from low MOE beams within a species, it is nevertheless effective in eliminating the beams with the very lowest MOE values. This finding is directly pertinent to engineering design: one of the major differences between tropical hardwoods and temperate softwoods is that, in general, the hardwoods are much stronger (MOR values are higher) than the softwoods, but there is not a corresponding increase in stiffness (MOE). In other words, the MOE/MOR ratio is lower for tropical hardwoods than for softwoods. The implication of this in engineered uses of wood is that designs are more likely to be governed by deflection and by stability than by strength considerations. This, in turn, means that particular attention will have to be paid to bracing details for tropical hardwood members subject to compression stresses.

(g) Small clear specimens in the air-dry condition have higher MOEs than green specimens. The effect is the same for full-size beams.

(h) There is a high correlation ($r^2 = 0.83$)

between beam MOE (MOE_b) and small specimen MOE (MOE_s):

$$MOE_b = 1.075\ MOE_s - 10{,}600\ kg/cm^2$$

considering all beams. Looking only at accepted beams, the correlation improves slightly ($r^2 = 0.87$):

$$MOE_b = 1.115\ MOE_s - 11{,}400\ kg/cm^2$$

(i) The corresponding correlations for MOR are not as good as for MOE. Considering all beams:

$$MOR_b = 0.552\ MOR_s + 65.4\ kg/cm^2\ (r^2 = 0.65),$$

i.e., small specimen MOR is not generally an effective predictor of beam MOR.

For accepted beams only:

$$MOR_b = 0.598\ MOR_s + 102\ kg/cm^2\ (r^2 = 0.89).$$

(j) Relating MOR to MOE, for the small clear specimens the correlation is high:

$$MOR_s = 1.011 \times 10^{-2}\ MOE_s - 302\ kg/cm^2\ (r^2 = 0.87)$$

whereas, considering all of the beams:

$$MOR_b = 5.42 \times 10^{-3}\ MOE_b - 7.17\ kg/cm^2\ (r^2 = 0.74).$$

This would indicate that the modulus of elasticity of beams is "not" a good predictor of modulus of rupture, which has implications for the efficacy of mechanical stress rating. On the other hand, considering only the accepted beams:

$$MOR_b = 5.40 \times 10^{-3}\ MOE_b - 15.9\ kg/cm^2\ (r^2 = 0.86),$$

which suggests that some combination of visual stress grading and mechanical stress rating (as is done by the glued-laminated timber industry in Canada) should be considered.

The foregoing are the overall results of the study. It is possible to go further and to look in detail at the effects of specific defects on strength, and to relate these findings to the Grading Rule. The reader may wish to refer to Table 18, which contains the most current provisions of the Grading Rule. (In most cases, the effect of these defects on MOE was slight and so, the stiffness results will not be considered further in the following paragraphs.)

Brittleheart

In 17 beams (3% of the total), brittleheart was found; in most cases it included the pith. Brittleheart produced average strength reductions of 20%, but these results were highly variable. It was decided to prohibit the presence of brittleheart.

Checks

Approximately 10% of the beams had drying checks. In no case did the presence of checks produce a significant strength loss. It was, therefore, decided to make the tolerance on checks fairly liberal as can be seen in Table 18.

Compression Failures

Preexisting compression failures (Fig. 10) generally caused severe strength losses. Of the 526 beams tested, 31 had compression failures (4 of Marupa, 18 of Catahua, 4 of Tornillo, 1 of Manchinga, and 4 of Estoraque). The frequency of this defect does not depend only on the species, but also on the source and the method of harvesting and transportation of the logs. On the average, it produced strength losses of 30%, with one value of the quality factor R_R being as low as 0.09. Another example of its deleterious effect, noted in the first phase of the Project, is illustrated in Fig. 10: of two almost identical Tornillo beams, one failed at an applied load of 5,140 kg; the other contained compression failures and failed at 720 kg. Compression failures are prohibited by the Grading Rule.

Decay

Decay is prohibited by the Grading Rule, although stains and other discolourations are permitted if the grader can be assured that they are not caused by fungal decay. When decay was located in highly stressed zones of the beam, it produced average strength reductions of 31%. Decay often accompanies other defects: pith, insect holes (as shown in Fig. 11),

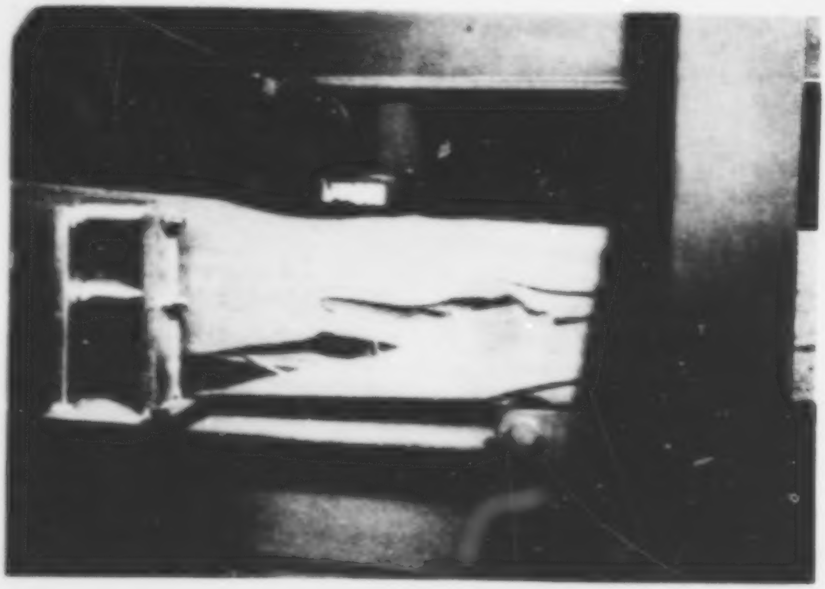

Fig. 9. Flexural failure in this beam was caused by local slope of grain around a large knot.

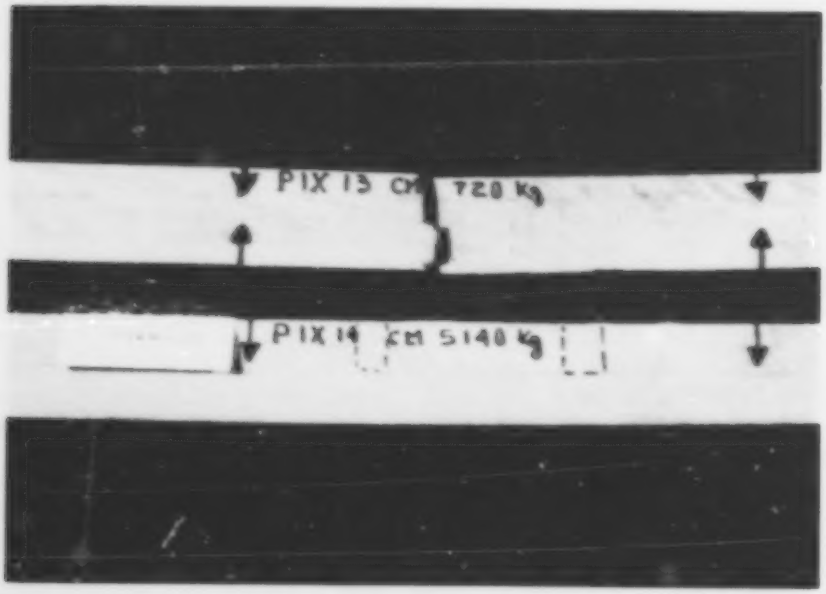
P IX 13 CM 720 Kg
P IX 14 CM 5140 Kg

Fig. 10. The effect of preexisting compression failures (upper beam) on bending strength.

knots, shake, checks, and end splits. These defects provide entry points for decay fungi into the member.

End Splits

End splits (Fig. 12) were found in 10% of the green beams and in 15% of the dry beams. Thirty beams had end splits greater than permitted. No significant strength reductions were found for the three beams in which failure appeared to be caused directly by an end split. It was felt, however, that end splits longer than those permitted by the Grading Rule could be a warning that other serious defects are present and, thus, the present limitation was kept, even though it is possibly conservative.

Insect Holes

After sloping grain, small insect holes were the most frequent defect, particularly in some species such as Manchinga (96% of the beams of this species displayed small insect holes) (Fig. 13). Considering all five species, 53% of the beams possessed this defect, accompanied frequently by decay (Fig. 11). In 103 cases (20% of the total), the holes were so abundant or so aligned that the beam was rejected under the Grading Rule. The influence of small insect holes was greater for low-density woods, particularly Marupa. For the beams of this species, the reduction in mean MOR, which could be attributed to small insect holes, was between 36% and 54%, depending on the location of the defect. In general, their strength reductions were greatest when they were located in the highly stressed zones of the beam.

Large insect holes were found in 45% of the Estoraque beams, 40% of the Tornillo beams, and less frequently in the beams of other species. Of the 526 beams, 15% had large insect holes acceptable under the Grading Rule and 6% caused the beams to be rejected. In these latter situations, the strength reductions ranged up to 26%. For the beams tested in the green condition, the worst location for large insect holes was the maximum compression zone; for dry beams, the critical location was the maximum tension zone.

Knots

One strength-reducing effect of knots is due to the local grain deviations that accompany knots, as

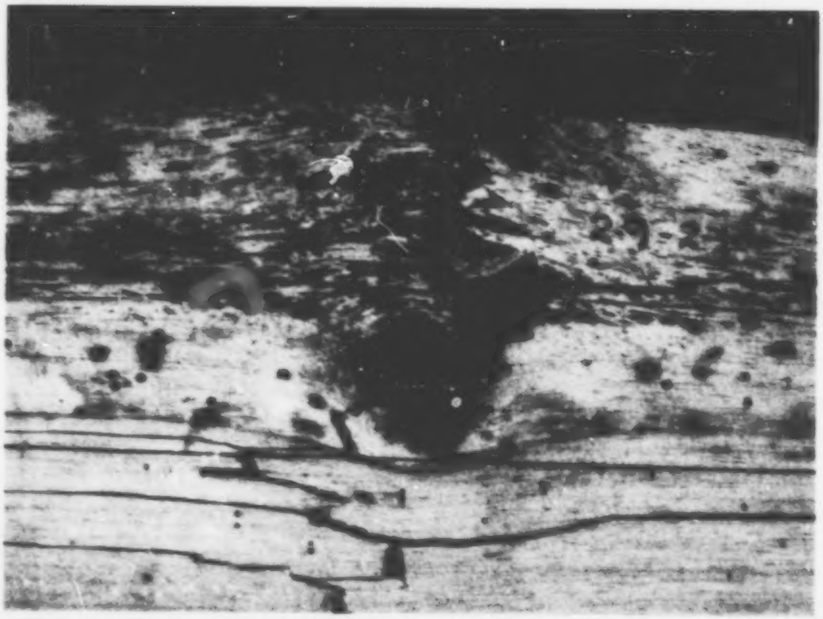

Fig. 11. An example of decay and small insect holes.

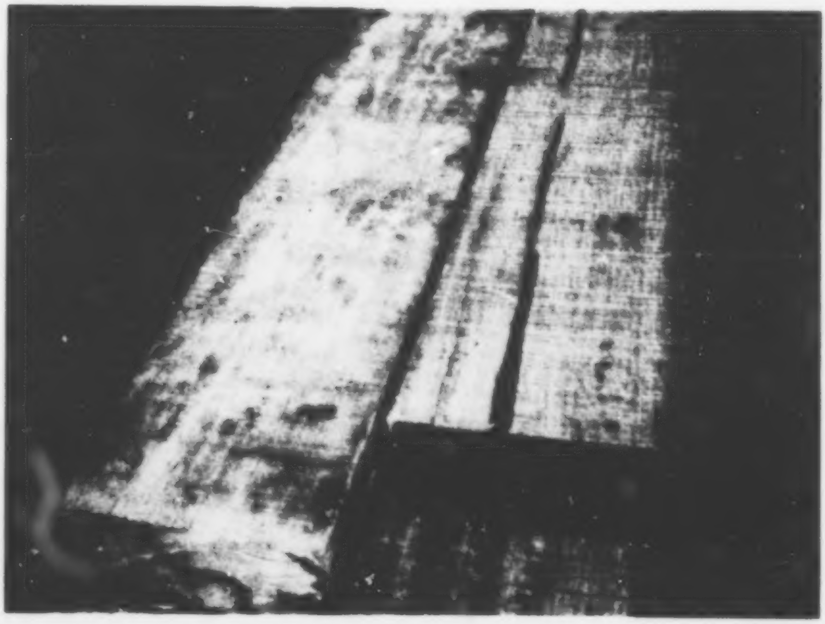

Fig. 12. End splits.

illustrated by Fig. 9. This is controlled by restrictions on knot size that are more stringent for loose (or decayed) knots than for tight knots. Tight knots were observed in 120 beams (23% of the total); in 40 of these, the knots were large enough to cause the beam to be rejected. Knots that were loose or decayed were found less frequently: only 14% of the beams, with most occurring in the dry beams. Sound knots had their greatest strength-reducing effect on green beams when located in the maximum compression zone, and on dry beams when located in the maximum tension zone. Strength reductions due to unacceptable sound knots were 37% on the average, ranging up to 43% for the tension zone. However, for acceptable sound knots there were no strength reductions except when the knots were located in the maximum shear stress zone, where there was a 12% reduction, indicating that the present rules may be excessively conservative. For loose knots (or deteriorated or attacked knots), the critical location is the maximum tension zone for both green and air-dry beams. Their effects were appreciable in other highly stressed zones. Unacceptable loose knots produced average strength losses of up to 38%.

Pith

The problem with pith is that it is usually surrounded by a zone of relatively weak, nondurable, and brittle wood (Fig. 14). It was originally permitted, under certain conditions, by earlier versions of the Grading Rule but is now prohibited. Approximately 8% of the beams contained pith that, in 60% of the cases, was decayed. Knots accompanied the pith in 88% of the cases. Inclusion of pith can greatly affect strength because of its frequent association with decay: up to 50% reductions in some species were found.

Shake

This is a separation between the annual rings that extend both tangentially along the ring and longitudinally with the grain. Shake was noted in 4% of the green beams and 13% of the dry beams. This defect caused problems when it appeared simultaneously on a wide and a narrow face of the piece (28% of the cases) or if it were accompanied by decay (26%). Unacceptable levels of shake produced strength reductions of up to 60%. Also, beams with acceptable levels of shake had

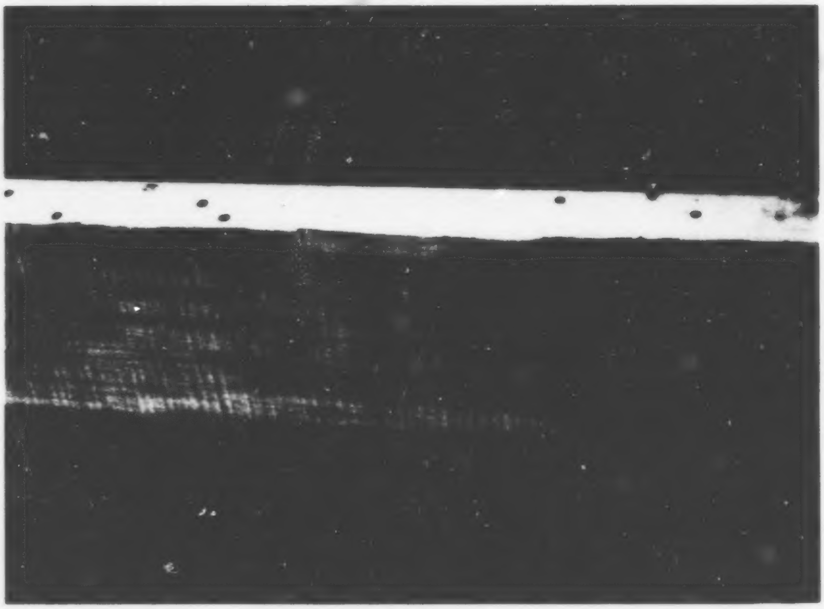

Fig. 13. Small insect holes.

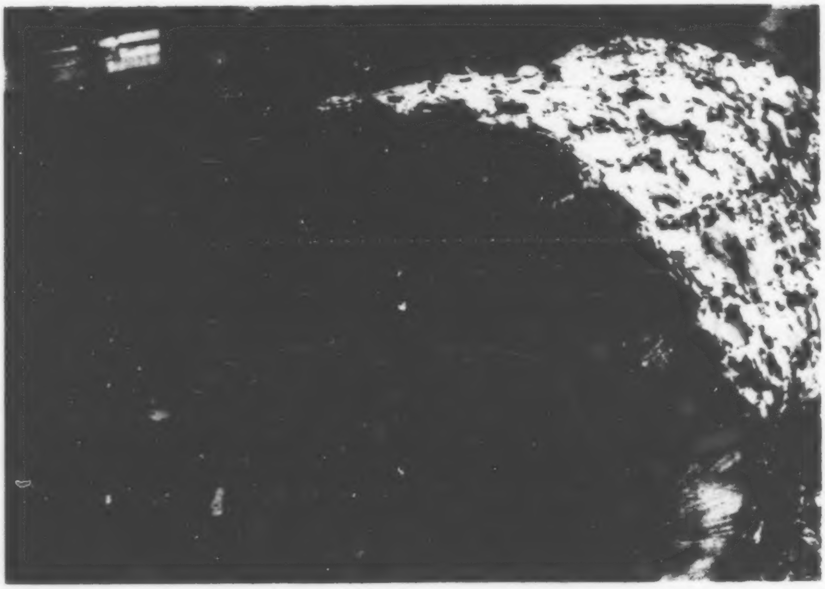

Fig. 14. The poorer wood around the pith can be seen here.

lower strengths, but this appeared to be due to the association of shake with other defects.

Sloping Grain

Because of its frequency and its influence on strength and stiffness, sloping grain was the most important defect in the beams studied. Approximately 70% of the beams tested had sloping grain of various amounts. In 190 beams (36% of the total), the slope was greater than 1/8, which is the limit of acceptability. The earlier editions of the Grading Rule permitted greater slopes in the less heavily stressed zones of the beams; however, because the Rule applies to all types of structural members, and because the continuity of grain direction and crack propagation along the length of the beam allows slope of grain characteristics in the outer thirds of the beam to influence middle-third behaviour, the 1/8 limitation is now used throughout the member. The test results showed that beams with slope of grain in the middle third of the beam greater than 1/8 had average MORs between 10 and 44% less than the corresponding straight-grained beams, and average MOEs between 9 and 28% less (this was one of the few defects that had a significant effect on MOE).

Sloping grain effects were slightly different for the radial plane compared to the tangential plane, but the differences were small enough not to be reflected in distinctions in the Grading Rule. Slope of grain restrictions apply also to small areas and to localized situations (particularly on the edges of the piece) and not just to the overall slope of grain.

Warp

Various forms of warp were removed during the planing of the beams before testing. Nevertheless, bow was encountered in 27% of the beams and crook was found in 12%. Twist and cup were not seen. Crook had no effect on mechanical properties but bow might have contributed to lateral-torsional buckling even though only 18% of the bowed beams failed in this manner. For bow, crook, and twist, the limit is the same: not more than 0.3% of the length of the piece. It could be argued that this limit is overly conservative when applied to bending members; however, the rules are general - they apply to columns as well as to beams -

and the amount of out-of-straightness for columns can have a critical influence on its axial compressive capacity.

Returning to the first subobjective of this study, which was to revise the Grading Rule as suggested by the test results, all of the test data were reviewed in June 1983, with particular attention being paid to the 13 beams that had been accepted by the Grading Rule but displayed MOR or MOE values lower than desired. Virtually all of these anomalies were cleared up. In some cases, it was discovered that the Grading Rule had not been applied properly (or rigorously enough) to the beams, and that a correct regrading would indeed move the beam from the "acceptable" to the "reject" category. In other cases, it was found that some defects had a greater strength-reducing effect than had been originally suspected; the Grading Rule was changed accordingly.

The second subobjective was to check the allowable stresses for each species group. When the beams were regraded correctly according to the revised Grading Rule, all of the acceptable beams of Tornillo, Manchinga, and Estoraque had adequate factors of safety compared to the allowable bending stresses and MOE values for species groups C, B, and A, respectively. Thus, no changes were made to the allowable stresses and MOE values for species groups A, B, and C. However, Marupa and Catahau did not meet the requirements for species group C. Rather than lower the allowable stresses for group C to accommodate these two species, it is recommended that a fourth group, group D, be established in the future. Initially, there would be only two species in this group; however, more will be added later, particularly as more low-density plantation-grown species are studied.

Grading Manual

The Grading Manual is a JUNAC publication entitled "Manual de Clasificación Visual para Madera Estructural." The most important part of this publication is the Grading Rule itself; the provisions of the most recent version are in Table 18. In addition to the individual defect restrictions, there is also a requirement that deals with combinations of defects, as follows:

> In some cases, the simultaneous presence of more than one defect of maximum permissible size or extent can produce a greater reduction in strength than any of the defects if present alone. If, within any of the following groups, more than one defect of maximum permissible size is present, the piece is rejected: (a) cup, bow, crook and twist; (b) general slope of grain and knots; (c) end splits, checks and shakes; (d) small and large insect holes.

Also present in the Grading Manual are sketches and photographs that will help the wood user to identify the defects referred to in the Grading Rule. It also shows how to measure the defects.

There is a section in the Grading Manual on wood structure, anatomy, and lumber terminology. Another section describes how to control or minimize defects in lumber; this deals separately with the effects of genetics, biological attack, wood processing, and wood drying.

General Comments on Grading

The first step in developing a visual stress grading rule for lumber could take place right at the sawmills and in the lumberyards: it is the recording of the defects in the lumber as it comes from the saw and after it has been air-dried in the yard. This survey results in a series of observations on what types of defects can be found in various species, their sizes, locations, frequencies, and their species-dependency. Having this information, it is possible to predetermine the percentage of lumber production that will pass the Grading Rule, which is often a political and marketing decision as well as a technical one. For example, the Andean Pact Grading Rule results in approximately 40-45% of the lumber produced meeting the requirements of the Grading Rule.

Sawmill surveys should be repeated in the future, because it is quite likely that defect-frequency occurrences will change with time. For example, it is possible that sawing techniques may change as greater amounts of construction lumber are produced. It is also possible that log characteristics will show greater variability as the exploited forest resource is expanded, and as more plantation-grown material is utilized.

Grading rules should be simple. Attempts to define precisely a series of strength grades are usually thwarted by the high variability of wood and the poor ability of many stress grading rules to predict strength. It is better to have only a few grades and to make the rules easy to understand and use, even at the risk of not using wood as efficiently as possible. Greater efficiency will come in future with the introduction of machine stress grading.

Long Duration Tests

A series of full-size, in-grade beams are being subjected to long duration load tests at LADIMA. They are covered over by a roof structure but are otherwise fully exposed to ambient temperature and humidity conditions. The beams are subject to various proportions of the design load. Three types of information are being sought: (a) the amount of deflection of the beams that occurs over extended periods of time, i.e., creep; (b) whether any of the beams fail under the sustained load; and (c) the remaining static bending strength remaining in the beams after being unloaded at some time in the future.

STANDARD LUMBER SIZES

The topic of standard lumber sizes is capable of providing more heated debate among wood users and wood producers than any other, with the possible exception of prices. One reason for this is that there are so many different ways to go about choosing a set of standard lumber sizes. Some of the choices facing the Andean Group Project personnel were to: (a) simply adopt a well-established set of sizes from another part of the world; (b) consider using preferred number theory to provide a rational series, as described by Booth (1967) and Keenan (1978); and (c) resaw all smaller standard sizes from larger standard sizes, e.g., (Madsen and Centeno 1978), leaving a 10 mm allowance for saw kerf shrinkage and planing.

The standard sizes that were finally selected were influenced by all three of the above approaches. They are shown in Table 20 along with the likely uses of each size. Also taken into account were the relationship of these sizes to what is already in the market and the necessity of providing a sufficient (but not excessive) number of sizes suitable for housebuilding.

The sections listed are those of dry lumber after planing. They are closely related to North American standard sizes as shown in Table 20, which is an essential consideration if exports are to be contemplated. In most cases, they are slightly larger than the North American sizes, which is useful considering that they will shrink additionally in the dry residential interiors in Canada and the United States.

It is interesting to explore the possibilities of resawing smaller standard sizes from larger standard sizes, assuming that 10 mm is lost with each cut. To illustrate, one could start with the largest standard size of 14 x 29 cm and cut it once to produce a 14 x 9 cm and a 14 x 19 cm size. These can each be cut so that

Table 20: Comparison of JUNAC and North American Standard Lumber Sizes

Dimensions (cm)		
JUNAC	North American	Common uses
4 x 4	3.8 x 3.8	Studs
4 x 6.5	3.8 x 6.4	Studs, joists
4 x 9	3.8 x 8.9	Studs, joists, columns
4 x 14	3.8 x 14	Joists, beams
4 x 16.5	-	Joists, beams
4 x 19	3.8 x 18.4	Joists, beams
4 x 24	3.8 x 23.5	Joists, beams
6.5 x 6.5	-	Columns
6.5 x 9	6.4 x 8.9	Columns, beams
9 x 9	8.9 x 8.9	Columns
9 x 14	8.9 x 14	Columns, beams
9 x 19	8.9 x 18.4	Beams
9 x 24	8.9 x 23.5	Beams
9 x 29	8.9 x 28.6	Beams
14 x 14	14 x 14	Columns
14 x 19	14 x 19.1	Beams, columns
14 x 24	14 x 24.1	Beams
14 x 29	14 x 29.2	Beams

the 14 x 9 cm produces a 4 x 9 cm and a 9 x 9 cm, and the 14 x 19 cm produces a 4 x 19 cm and a 9 x 19 cm. These latter two can be cut in half to produce two 4 x 9 cm and two 9 x 9 cm pieces.

FASTENINGS AND JOINTS

Proper jointing of structural members is possibly the most important, but most difficult, aspect of timber construction. There are many types of fastening devices for wood construction: nails, bolts, screws, staples, split ring connectors, shear plate connectors, toothed plates, truss plates, glulam rivets, and glued joints such as scarf joints and finger joints. There are also many indigenous types of fastening devices like dowels, vines, lianas, etc.

A choice had to be made as to which types of fastenings should be tested in the Project, and it was the most common ones - nails and bolts - that were chosen. The methods of ASTM Standard D1761, "Standard Methods of Testing Metal Fasteners in Wood," were used because they provide a relatively straightforward way of measuring static resistance to normal forces and can form the basis for building code allowable values, both parallel to the grain and perpendicular to the grain.

The research was carried out in six laboratories in the five countries. The final processing of the information and the preparation of the reports were done at LADIMA and in the central office of PADT-REFORT.

Nailed Joints

Work on nailed joints is reported in "Ensayos de Uniones Clavadas con Maderas de 49 Espécies de la Subregion Andina" (Tests on Nailed Joints with 49 Wood Species of the Andean Group).

Forty-nine different species were chosen from the subregion to include densities ranging from very low to medium: basic relative densities varied from 0.21 to 0.65. Of the species, 45 were hardwoods, three were native conifers (Podocarpaceae family), and one was an exotic conifer (Pinus radiata). They were grouped as follows:

Group	Range of basic relative density	Number of species
B	0.55-0.65	9
C	0.40-0.55	23
D	0.21-0.40	19
Conifers	0.39-0.57	4

Ten trees were used for each species, with two samples being cut from each tree. Twenty replications were tested for each nail length of each species. Specimens were assembled and tested in the green condition.

Each test specimen was of the double shear compression type, which consists of two side members and a central (main) member, all 4" wide x 14" long. The thickness of each side member is equal to half the thickness of the main member. The main member is displaced longitudinally 50 mm from the side members so that it sticks out above them in the testing machine. The specimen is loaded in compression in a testing machine such that the load is applied to the top of the main member, and the specimen is supported on the bottoms of the side members. Four smooth shank nails were used in each specimen; they passed all the way through from one side of the specimen to the other, i.e., the total thickness of the specimen was equal to the length of the nails. Two nail lengths, 2.5" and 4", were used in each country. However, each country produces its own types of nails and there was no single type and size that was common to all parts of the subregion. The various nail diameters (mm) were:

Country	Length = 2.5"	Length = 4"
Bolivia	2.5	3.8
Colombia	3.0	5.2
Ecuador	3.4	5.2
Peru	3.2	4.0
Venezuela	3.3	4.9

Two dial gauges were mounted on each specimen to measure the slip between the main member and the side members. The two readings were averaged and used to plot a load vs. slip curve for each specimen. From the curves, the load corresponding to a slip of 0.38 mm and the maximum load were recorded. Test durations were between 5 and 20 minutes.

The load-slip curves were nonlinear right from the beginning, making it difficult to pinpoint a proportional limit. Therefore, the traditionally used slip of 0.38 mm (0.015") was selected instead.

The loads at 0.38 mm slip and at ultimate had high correlations with the density of the wood and the diameter of the nail, as follows: symbols and units - load P (kg), basic relative density DB, and nail diameter d (mm).

Mean values:

$$P_{0.38} = 66.0\ DB^{1.022}\ d^{1.232} \qquad (r^2 = 0.74)$$
$$P_{max} = 146.2\ DB^{1.214}\ d^{1.451} \qquad (r^2 = 0.75)$$

Minimum values:

$$P_{0.38} = 57.5\ DB^{1.269}\ d^{1.451} \qquad (r^2 = 0.66)$$
$$P_{max} = 136.6\ DB^{1.365}\ d^{1.131} \qquad (r^2 = 0.72)$$

The average ratio of $P_{max}/P_{0.38}$ was in the order of 2.25 for the less dense species with a nail length of 2.5". For higher densities, and for the 4" nails, this ratio was larger.

Consideration was then given to choosing the factor of safety to be used in deriving allowable loads from the test data. Two design conditions (or limit states) were identified: the slip of 0.38 mm as indicating the onset of inelastic behaviour in the joint, and the failure load. Against $P_{0.38}$, a factor of safety of 1.8 was chosen to take into account variability, population size, workmanship, uncertainties concerning the applied loads, and the possibility of overloads. Against failure, a factor of safety of 3.0 was chosen taking into account the above considerations as well as the effects of load duration.

Each design load will be the lesser of the two calculated in the foregoing. In most cases, it appears that the failure load divided by 3.0 will give the governing value.

Bolted Joints

The results of this work appear in "Ensayos de Uniones Empernadas con Maderas de 46 Espécies de la Subregion Andina" (Tests on Bolted Joints with 46 Wood Species of the Andean Group).

Forty-six different species were chosen from the subregion to include densities ranging from medium to very high (0.42-0.89) and were grouped as follows:

Group	Range of basic relative density	Number of species
A	0.70-0.90	14
B	0.55-0.70	27
C	0.40-0.55	10

Ten trees were used for each species, with two samples being cut from each tree. Twenty replications were tested for each bolt length for each orientation of load to grain for each species. Specimens were assembled and tested in the green condition.

All specimens were of the three-member double-shear compression type consisting of a middle (main) member and two side members. The thickness of each side member was equal to half the thickness of the main member. Two orientations of load to the grain direction of the main member were used: parallel and perpendicular. The parallel specimen comprised three pieces 3" wide x 6" long of variable thickness. The grain direction of all three pieces was vertical and the main member was displaced longitudinally 50 mm from the side members. A single bolt passed through the three members and was fastened using two washers and a nut. As with the nailed joint specimen, compressive load was applied to the top of the main member, and the specimen was supported on the bottoms of the side members. Two dial gauges were mounted to measure the slip between the main and side members.

The perpendicular to grain specimen consisted of a horizontal 3" wide x 12" long main member that rested on supports providing a 9" clear span. The side members were vertical, 3" wide x 8" long, and load was applied to their upper ends. Two dial gauges measured slip. A single bolt fastened the specimen as before.

All bolts were 1/2 in. diameter. Three lengths were used: 2", 4", and 8", yielding ratios of the length of the bolt in the main member to bolt diameter (l/d) of 2, 4, and 8, except in Venezuela where l/d ratios of 2, 4, and 6 were used. Wax paper was placed in the interfaces of the members to reduce the unwanted contribution of friction to the strength of the test specimens.

The bolts were tightened with a wrench, then the nut was backed off and retightened using finger pressure. Load was applied and the corresponding average slip was recorded, to produce a load vs. slip curve for each specimen. Test duration was between 5 and 20 minutes.

The load-slip curves were initially more linear than those of nailed joints and, thus, a distinct proportional limit could be identified. Therefore, two values were recorded: load at proportional limit P_{PL} and maximum load P_{max}.

Analyzing the results, it was noted that for short bolts (l/d = 2) the correlation of load with density (DB) was better than that with the parallel or perpendicular to grain strength of the wood, as applicable. Using a linear regression:

Parall[illegible] grain loading:

[illegible]$_{L}$ = (649 DB - 137.2) ld ($r^2 = 0.67$)
[illegible]$_{ax}$ = (1310 DB - 289.4) ld ($r^2 = 0.71$)

Perpendicular to grain loading:

$$P_{PL} = (482\ DB - 140.1)\ ld \qquad (r^2 = 0.74)$$
$$P_{max} = (801\ DB - 167.8)\ ld \qquad (r^2 = 0.52)$$

For longer bolts, the unit capacity at the proportional limit decreases as l/d increases. The reduction is greater for the denser woods, and is less for ultimate loads than for proportional limit loads, with almost no effect for maximum perpendicular to grain loading.

If we take $S = P/ld$ to be bearing stress and S_o to be the short bolt bearing stress ($l/d = 2$), the reduction factors can be expressed by the ratios S/S_o. Considering all species together:

Parallel to grain loading:

$$(S/S_o)_{PL} = 1.860\ (l/d)^{-0.623} \leq 1 \qquad (r^2 = 0.65)$$
$$(S/S_o)_{max} = 1.971\ (l/d)^{-0.490} \leq 1 \qquad (r^2 = 0.60)$$

Perpendicular to grain loading:

$$(S/S_o)_{PL} = 1.699\ (l/d)^{-0.422} \leq 1 \qquad (r^2 = 0.32)$$
$$(S/S_o)_{max} = 1 \text{ (approx.)}$$

The ratio of P_{max}/P_{PL} displayed great variability; for short bolts, the value is in the order of 2 with higher values for longer bolts. The approach to determining allowable loads was the same as described earlier for nailed joints.

Possible Future Research

After the initial standard testing of nails and bolts has been completed, there remains a tremendous amount of research that can be done on joints for wood construction. Some of the topics are the following:

(a) For countries subject to earthquakes, attention should be paid to the ductility, fatigue, and energy-absorbing characteristics of wood joints during seismic loading.

(b) For countries with high humidity, there can be a problem with the corrosion of metal fasteners. Several aspects can be involved: general corrosion (oxidation) of the metal, chemical corrosion of the fasteners due to a combination of moisture and chemicals in the wood, and degradation of the wood itself (nail sickness) due to chemical attack by corrosion by-products. For this purpose, it is suggested that test specimens be set aside in various environments for varying periods of time, and then examined and tested in an attempt to detect loss of strength over time.

(c) It is known that the capacity per connector decreases as the number of connectors in a joint increases. Thus, joints of varying sizes and configurations can be tested to measure this size effect.

(d) What are the effects of direction of load with respect to grain angle, of wood moisture content, of duration of load, and of wood density, on joint strength?

(e) If wood densities are not too great, the use of truss plates can be investigated. These metal plates with integral teeth are invaluable for the economical in-plant fabrication of light roof trusses.

(f) Glued joints (both in-plant and on-site) can be developed but only if a high degree of quality control is achievable.

(g) High-density hardwoods might be used in place of steel in joints, either as dowels or as discs, which act like split ring connectors.

STATIC AND DYNAMIC TESTS ON STRUCTURAL COMPONENTS

Two important types of structural components have been tested in the Project: shear walls and roof trusses. This work was done in the LADIMA laboratory in Lima, which was built for, and during, the Project.

Shear Walls

Discussed here are static tests on shear walls; dynamic tests are dealt with later. The pertinent JUNAC report is "Ensayos Preliminares de Paneles de Corte" (Preliminary Tests on Shear Walls); it describes a series of "racking" tests in which a full size wall unit was constructed (with various methods of framing, bracing, and sheathing) and a concentrated statically applied horizontal load was applied at the top corner (Fig. 15). This particular test measures the resistance of the wall to wind and earthquake forces.

Deformations are measured during the test until failure occurs; design values for lateral loads are based on the load vs. deformation curve of the panel. However, there are some indications that the method of test tends to overestimate the actual performance of walls under earthquake loading. It is suggested that there is a hysteresis effect on the panels due to repeated loading, i.e., the fasteners yield under load in one direction and this is not recovered in subsequent parts of cyclic loading. It is, therefore, recommended that cyclic loading, rather than monotonic, be used for the seismic assessment of wall panels. Some current thinking is that four cycles prior to failure should be sufficient.

In the testing program, sixteen 2.4 x 2.4 m wall panels (Fig. 16) were subjected to a slowly applied horizontal racking load. Load was applied in four

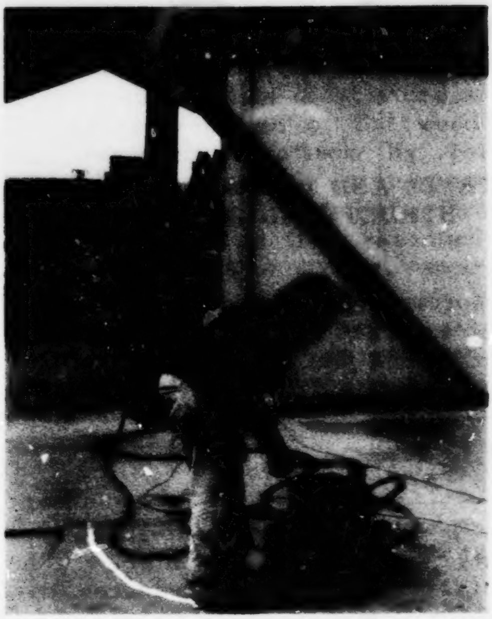

Fig. 15. Static load test on a shear wall.

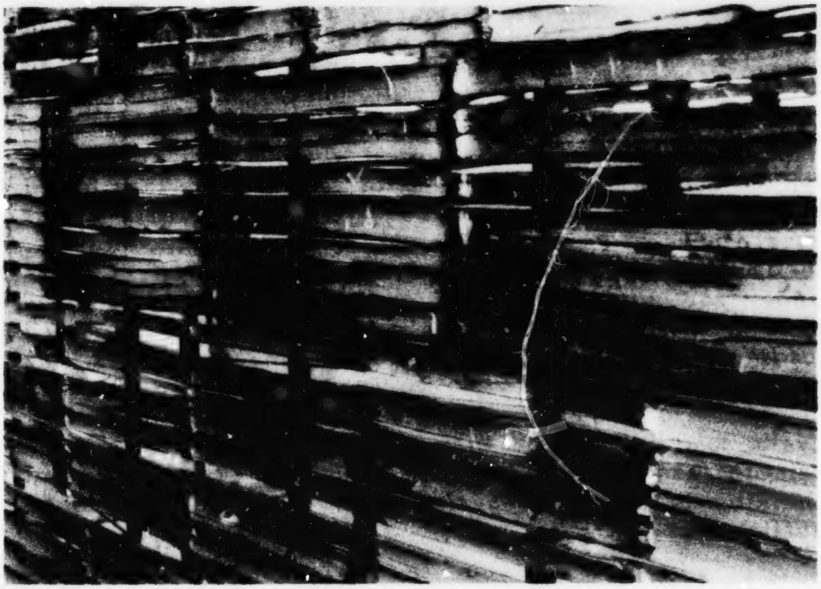

Fig. 16. A vernacular wall system tested at LADIMA: split bamboo nailed to studs.

cycles of increasing load up to failure. Graphs of applied load vs. deformation were plotted, and values of stiffness and maximum load were obtained from this. Each panel was different; variables included spacing between studs, presence and type of diagonal bracing, presence of door and window openings, presence and type of wall covering, and nail size and spacing. It was found that wall sections covered with wood-based panels are quite stiff but their strength is governed by the number and spacing of the nails. The diagonal braces were not particularly effective. Comparable to the behaviour of wood-based panels are walls covered with wood lath and gypsum plaster. As expected, door and window openings greatly reduce strength and stiffness. Of little influence were stud spacing and panel thickness.

The process of deriving allowable loads for shear walls consisted, first, of identifying the limit states to be considered during design. Decided upon were: (a) a horizontal displacement of 2 mm, and (b) failure of the panel.

Condition (a) corresponds to the situation when the wall panel is subject to the maximum design wind load and to "moderate" earthquakes, i.e., ones that may occur several times during the life of the structure. Condition (b) corresponds to strong earthquakes, i.e., ones that exert a seismic force equal to 10% or more of the weight of the house.

Factors of safety chosen against these two conditions are: against (a) = 1.0, and against (b) = 2.1. These calculations were performed for all of the wall panels tested and the results will appear in Chapter 10 of the Design Manual report prepared by JUNAC. Also to be included is a design example illustrating, for a typical house, how the seismic loads and shear wall resistance are computed.

Roof Trusses

The truss testing facility is a cable and pulley apparatus (Fig. 17). JUNAC's report on this work is "Ensayos Preliminares de Tijerales" (Preliminary Truss Tests), which presents the results of 12 exploratory

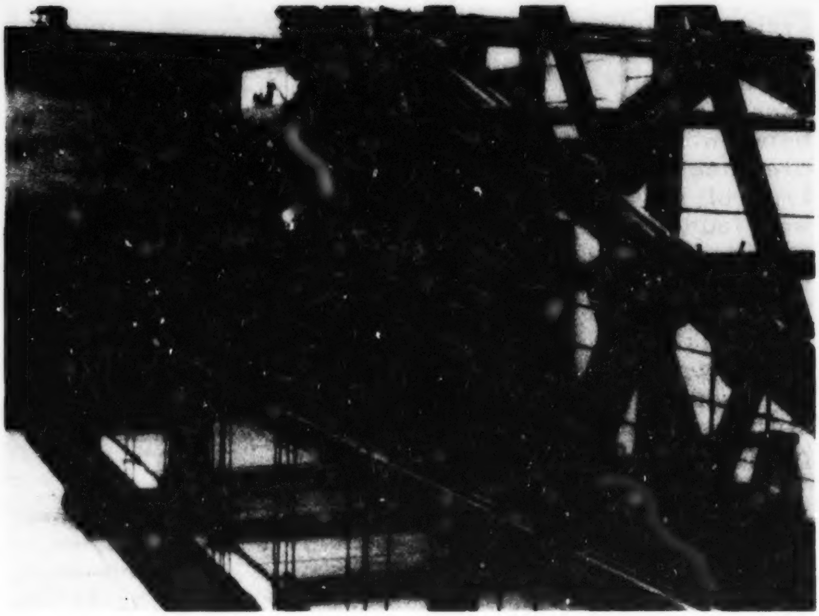

Fig. 17. Load test facility for roof trusses, LADIMA.

tests on roof trusses. They were conducted largely to debug the test rig before more extensive testing programs being carried out on behalf of individual countries. Five of the 12 trusses tested carried much lower maximum loads than they should have carried. In some cases this was due to plywood gussets failing in shear. It was also found that lumber splices did not work very well if not detailed properly. Otherwise, the remaining truss designs provided adequate factors of safety and this information will be made available to designers through Chapter 11 of the Design Manual.

Another set of truss tests was conducted at LADIMA, but these were for Peru, not for the Project. This latter group comprised some 96 trusses, four replications of each of 24 designs. Test parameters were: species - Tornillo; spans - 6 m, 8 m; configuration - W (Fink); roof slope - 3/12, 5/12; and moisture content - assembled green, tested air-dry. The variables were member thickness and depth, arrangement of members, thickness of lumber gussets, and number and length of nails.

Factors of safety were agreed upon as for shear walls, the trusses were grouped into "families," and allowable load/span tables were constructed. This information will go into a future edition of the Design Manual.

Dynamic Testing

The Project researchers have constructed a seismic test facility at LADIMA. The tester provides one mode of movement (one translation) with separate control over amplitude, frequency, and functional shape of the excitation, with specimen movements being sensed using accelerometers. The shaking table on which the house, or house module, sits is 4.8 x 4.8 m (Keenan 1980). The shaking table is driven by an actuator that is controlled by a microcomputer in the control chamber. This can test either two-thirds scale houses (Fig. 18) or full-size wall panels.

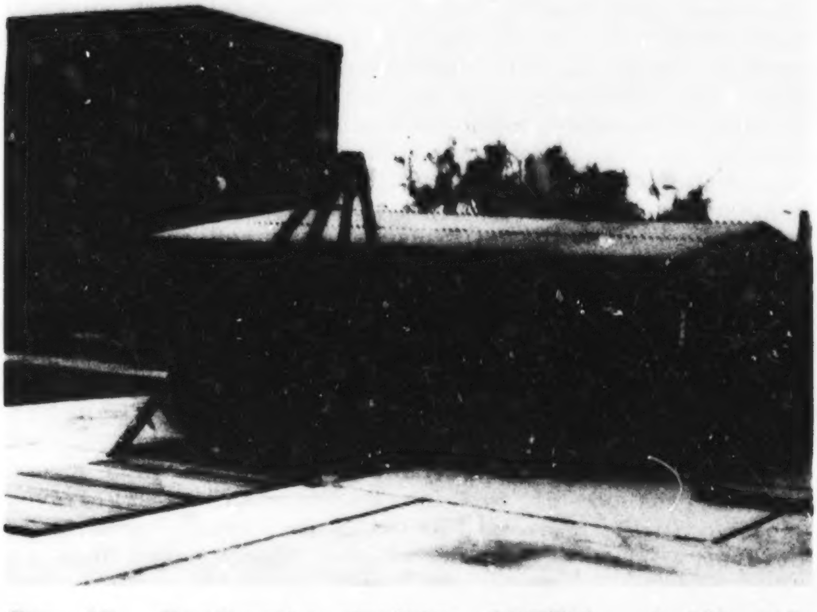

Fig. 18. Earthquake simulator, LADIMA. A 2/3 scale house is on the shaking table. The control chamber is behind and to the left.

The JUNAC report "Ensayos Dinámicos de Paneles con Entramado de Madera y Diversos Revestimientos" (Dynamic Tests on Timber-Framed Panels with Various Coverings) presents the results of dynamic tests performed on nine full-size (2.4 x 2.4 m) wall panels, each made in a different way. Three different wall coverings were used: sugar cane bagasse board, wood lath covered with gypsum cement, and expanded metal mesh covered with cement mortar.

For each type of wall covering, three panels were made: one without openings, one with a window opening, and one with a door opening. Each panel was mounted on the seismic tester and was subjected to free vibration tests to determine its natural period of vibration and its damping coefficient. The free vibration test was run three times with an increasing superimposed mass riding on the top of the panel to represent the weight of the joints and other materials that would be supported by the wall in service. Two of the three coverings performed well: the sugar cane bagasse board and the wood lath covered with gypsum cement. The panels with expanded metal mesh covered with cement mortar did not perform well; they exhibited severe cracking and spalling away of the covering. This was probably due to the poor shear connection between the metal mesh and the framework.

Comparing these dynamic results with the corresponding results of the static tests on wall panels, it was found that the stiffnesses measured in the static tests were not at all in agreement with those derived from the dynamic tests. The disagreement is probably due to the influence of the forces produced by the restraint rods in the static tests.

HOUSING DEVELOPMENT AND CONSTRUCTION

The actual construction of housing is the main activity of the second phase of the Project. It is hoped, ultimately, to construct 500 houses, 100 in each country. At the time of writing, 15 have been built and one is under construction: Santa Cruz, Bolivia, 3; Pacullpa, Peru, 1; LADIMA, Lima, Peru, 2; Canto Grande, Lima, Peru, 1; Conocoto, Ecuador, 2; Esmeraldas, Ecuador, 2; Guayaquil, Ecuador, 1; Cartagena, Colombia, 2; Bogota, Colombia, 1; and Guarenas, Venezuela, 1; for a total of 16.

The background to this activity goes back a few years. A young Peruvian architect who was working in the Project was granted an IDRC fellowship to gain both formal training and practical experience in wood construction. With additional financial support from JUNAC, he first took the postgraduate course in Wood Structures and Technology at the Imperial College of Science and Technology in London. This was followed by periods of work with a timber engineering company in the U.K. and with a premanufactured housing operation in western Canada. He then returned to the project and is now the head of the architectural design team. One of his accomplishments was to provide the technical coordination for feasibility studies of wood housing in each of the five countries. Among other things, this culminated in five prototype house designs. They have in common the use of sawn wood for the structural framework of the walls and roofs. Where they differ is in the interior and exterior wall coverings. Encompassed in the 15 houses already constructed are: metal mesh covered with plaster, gypsum board, wood cement board, split cane covered with plaster, asbestos cement, wooden boards, wood fibre covered with plaster, and particleboard covered with stucco.

The feasibility studies were quite thorough. Some of the points that were studied are:

(a) The existing housing situation in various areas of each country - the currently acceptable and preferred forms of housing, land and building costs, the housing deficit, income distribution in the population and the corresponding ability to pay for shelter, i.e., a market study.

(b) Appropriate locations in each country for wood housing projects and the selection of sites for pilot projects of 100 houses each.

(c) Financial resources available to fund pilot housing projects.

(d) Legal and political aspects - existing building codes and standards, government attitudes, policies, and priorities.

(e) Draft proposals of building codes for wood construction.

(f) Draft proposals for modular coordination.

(g) House typologies in each area and the selection of optimized house designs using wood.

(h) Geoclimatic conditions of each site.

(i) Site layout and landscaping. The provision of attractive landscaping, without substantially increasing costs, was an essential part of the pilot studies because it contributed so much to an overall favourable appearance to wood housing. For example, many of the existing trees on a site were retained and house locations were arranged to accommodate attractive trees.

What the feasibility studies concluded was that, in each country, it was possible to build attractive and acceptable wood houses that are economically competitive with existing housing of comparable quality. Moreover, these cost advantages are predicted to increase as experience is gained in wood construction and as economies of scale come into play. At the very least, wood construction was shown to be a feasible alternative to existing forms of construction.

Unfortunately, however, not all levels of society in the subregion can benefit at the present time from this development work. We pointed out earlier that there was an existing strong prejudice against wood construction. To counter this, the Project had to demonstrate that wood housing was attractive, safe, and durable; it had to be shown to be technically sound, economically competitive, and financially supportable. Such efforts were more likely to be successful if the initial market were not the lowest income families. In the future, this development can be progressively tailored to the low-income segments of society.

TECHNOLOGY TRANSFER, EDUCATION, AND TRAINING

"The concern for man and his destiny must always be the chief interest of all technical effort. Never forget it among your diagrams and equations."

Albert Einstein

Technology Transfer

Finally, having developed all of the technology described in the preceding chapters, one has to decide how to use it for the betterment of society. This is often the weakest link in technology projects. Researchers who excell in discovering new truths are not always the individuals who are most capable in ensuring that these truths are used widely and wisely. Therefore, the administrators of wood technology projects have a particularly demanding job in selecting the people who can best carry out technology transfer. Along with the researchers, one needs specialists in communications, professional educators, builders, building officials, practicing architects, and consulting engineers.

There are too many examples in the world where good research results simply gather dust on bookshelves. Because of the substantial body of prejudice against wood construction in many countries, it is difficult to overestimate the amount of work required to encourage wood construction. All of the obvious things have to be done - writing textbooks and design manuals for technical and professional students of construction, engineering, and architecture; organizing courses in the universities; presenting seminars to the design professionals; developing courses for the building trades; establishing technical and professional societies, product standards, and promotional associations; convincing financial institutions and the public of the durability and safety of wood construction; distributing useful design information to builders and designers, etc. But probably the most important step is for the governments to provide solid backing to these development efforts over a period of several years and to completely subsidize the construction of several wood buildings. One of the best ways to convince someone to use a new building material is to let it be seen in service for several years.

The most valuable outputs from a research and development program are the people who have gained the experience of working with wood. These people will have to be kept working with wood and will then form the nucleus of an expanding group of timber users. In fact, the development of a "critical mass" of timber people is possibly the most vulnerable step in a program of wood utilization in a developing country. To avoid technical inbreeding, courses should be made available, both nationally and internationally, to the project workers.

Design Manual

One of the most important achievements of the Project was the publishing of "Manual de Diseño para Maderas del Grupo Andino" (the Design Manual for Woods of the Andean Group). Assembled by Dr Javier Pique with contributions from many others, it covers all aspects of wood construction in the subregion and is one of the main vehicles for transferring research findings into the design and construction process. To give an idea of the breadth and depth of its contents, the following are the chapter titles: Wood Characteristics and Properties; Conversion, Drying and Protection of Wood; Wood as a Construction Material; Construction Planning; Construction Details; Protection by Design; General Design Considerations; Design of Bending Members; Design of Compression Members; Shear Walls; Light Trusses; Joints; Reference Information; Graphical Representation; Glossary; and Bibliography. Currently, the Manual exists as a third preliminary edition, and will be modified. In fact, because it will always have the job of transmitting the most up-to-date information, it will hopefully continue to be revised indefinitely.

Education

In terms of education, we are considering professional-level courses at universities that will produce the new leaders in the use of wood as engineering materials. These are often presented as programs in "Wood Science and Forest Products" or "Wood Science and Industries" within Faculties of Forestry. Also at universities are courses in Timber Engineering taught in Civil Engineering departments and Wood Construction courses in Architecture schools.

Training in Timber Grading

Almost all training in timber grading is done by the timber industry rather than by educational institutions. The following is a description of industrial training in visual lumber grading as conducted in a typical western Canadian sawmill. The instruction is given in the mill by a staff grader who is approved to teach grading by one of the grading agencies. The companies encourage their employees to take grading courses, which are given outside regular working hours. The "prize" is that production personnel become eligible for some of the better-paying jobs (e.g., sawyer, trim saw operator, edgers, graders). Management-stream people also take the courses; they don't immediately receive raises, but it adds to their prospects for promotion. The duration of the course is one or two evening sessions 2 hours long for 3 months. The aids used are books with descriptions and sketches of the defects, as well as a multiplicity of timber samples. In class, a limited number of samples are used but they are analyzed in depth. Outside of class, a set of 100 sample boards is available for individual practice.

The exam is 2-3 hours long and consists of a written portion plus a practical portion. In the practical portion, a number of sample pieces are presented to the candidate who is required to grade them correctly according to a particular rule. The examination is conducted by the grading agency; the agency also issues certificates to the successful applicants. There are no mandatory refresher courses or requalification examinations, although grading competitions are sponsored from time to time. For mechanically stress-rated lumber, it is generally the manufacturer of the machines who provides the training at the present time.

It is recommended, therefore, that:

- Although training course durations of 3 months are not uncommon for countries with well-developed grading systems, this is possibly more than necessary for the subregion. Perhaps 5 or 6 weeks would be sufficient. This shorter period would lessen the reluctance of the grader's employer to pay his or her wages during the grading course.

- The training should be done at the sawmill rather than at a research laboratory.

- As background preparation, it would be useful for the grader trainee to have had some previous practical experience in the sawmill. Furthermore, if a suitable aptitude test could be developed, this might help to screen out people who might not benefit from the training. Lacking this, a minimum level of education could be specified.

- Once the graders have passed the course, they should take pride in their accomplishment and, concurrently, be aware of the technical responsibility that they have now assumed. Because they have developed a skill, they should also receive some financial recognition because they are now capable of contributing more to their employer's success.

- With respect to instructional aids, those developed by the Timber Research and Development Association (TRADA) in the U.K., by the Malaysian Timber Industry Board, and by Australia could be used immediately as they are and subsequently modified to suit the needs of a particular country. The visual impact of the aids should be professionally developed making appropriate use of colour and animation.

FUTURE WORK

There are three particular directions that, hopefully, the technology developed in the Project can lead to in the near future. One is the construction of wood houses as discussed earlier that can, without sacrificing quality, become progressively less expensive as building experience is gained.

A second objective is to expand wood utilization research and development activities into other countries making use of the activities of the Project. Such a project is now getting under way in Paraguay. Its general and long-term aim is to establish the strength characteristics of lesser known Paraguayan timber species to achieve a better utilization of the natural forest resource and to promote the use of such species in construction, particularly in low-income housing. The specific objectives are:

(a) To determine strength and stiffness values for selected Paraguayan timber species of potential commercial interest.

(b) To relate visibly recognizable defects in the members to their strength and stiffness performance, and establish values for allowable bending stress; and

(c) To disseminate the practical results by the publication of simple visual stress grading rules, structural design charts, and the training of graders.

Arrangements have been made for researchers in the Andean Group Project to travel periodically to Paraguay to share their experiences.

The third future area of work is to devise projects that will be of direct benefit to the poor people of the subregion, particularly the rural poor. For example, the seismic test facility at LADIMA should be used to improve vernacular forms of construction in earthquake-prone areas.

REFERENCES

Booth, H. 1981. Methodology for incorporating new species in the design code. Lima, Peru, Junta del Acuerdo de Cartagena (JUNAC). (Unpublished report.)

Booth L.G. 1967. The application of preferred numbers to the determination of basic stresses, grades and sizes of structural timber. Proceedings, Meeting of IUFRO Section 4, September 1967. Munich, Germany, IUFRO.

Dourojeanni, M. 1981. Forestry and rural development in the Amazon. Toronto, Canada, University of Toronto, Faculty of Forestry, Weyerhaeuser Lecture, 4 November.

FAO (Food and Agriculture Organization of the United Nations). 1981. Yearbook of forest products. Rome, Italy, FAO.

FAO (Food and Agriculture Organization of the United Nations). 1972. Seventh World Forestry Congress. Rome, Italy, FAO.

Keenan, F.J. 1982. Training and inspection requirements for quality assurance of stress graded structural wood products. Report No. ID/WG.359/5. Vienna, Austria, United Nations Industrial Development Organization.

Keenan, F.J. 1980. The earthquake resistance of timber construction. Proceedings, International Conference on Engineering for Protection from Natural Disasters. Bangkok, Thailand, Asian Institute of Technology.

Keenan, F.J. 1978. Preferred sizes of structural lumber in the Andean Pact countries. Lima, Peru, Junta del Acuerdo de Cartagena (JUNAC). (Unpublished report.)

Leigh, J.J. 1984. Evaluation of cable logging systems in tropical mountain forests. Toronto, Canada, Faculty of Forestry, University of Toronto. (Thesis paper.)

Madsen, B. 1975. Strength values for wood and limit states design. Canadian Journal of Civil Engineering 2(3): 270-279.

Madsen, B. and Centeno, J.C. 1978. Structural lumber sizes for the Andean Countries. Report prepared for the International Development Research Centre, Canada.

Peru: Dirección General Forestal y de Fauna. 1980. Producción y valorización de los productos forestales de la madera.

Richards, P.W. 1973. The tropical rain forest. Scientific American (December).

Tejada, M. 1981. Summary PADT-REFORT. Proyectos Andinos de Desarrollo Tecnológico en el Area de los Recursos Forestales Tropicales (PADT-REFORT). Lima, Peru, Junta del Acuerdo de Cartagena (JUNAC).

Teng, I. 1971. Review of the use of wood in housing in Peru. Vancouver, Canada, World Consultation on the Use of Wood in Housing.

U.S. Interagency Task Force on Tropical Rain Forests. 1980. The world's tropical forests: a policy, strategy and program for the United States. Washington, D.C., Department of State Publication 9117.

APPENDIX A

MEAN PHYSICAL PROPERTIES OF THE WOOD OF 104 SPECIES OF THE ANDEAN GROUP

Abbreviations

CHV : moisture content of specimens in the green condition

CHSA : moisture content of specimens in the air dry condition

DV : green density

DSA : air dry density

DA : oven dry density

DB : basic relative density

CRN : normal radial shrinkage

CTN : normal tangential shrinkage

CVN : normal volumetric shrinkage

CRT : total radial shrinkage

CTT : total tangential shrinkage

CVT : total volumetric shrinkage

T/R : ratio of CTT to CRT

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm³	DSA g/cm³	DA g/cm³	DB g/cm³	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
1 **ACEITE CABIMO** Copaifera pubiflora CAESALPINIACEAE	VE	79	14	1.00	.67	.63	.56	1.4	3.3	4.6	3.4	7.1	10.2	2.1
2 **ACEITE MARIO** Calophyllum mariae GUTTIFERAE	CO	98	15	.91	.58	.55	.46	3.2	6.4	9.4	6.6	10.9	16.8	1.7
3 **AJO AJO** Gallesia integrifolia PHYTOLACCACEAE	BO	99	12	1.03	.64	.61	.51	3.7	6.3	9.8	6.3	9.9	15.6	1.6
4 **ALGARROBO** Hymenaea courbaril CAESALPINIACEAE	VE	53	13	1.18	.92	.88	.77	1.7	3.2	4.9	4.2	7.4	11.2	1.8
5 **ALMENDRILLO** Taralea oppositifolia PAPILIONACEAE	BO	41	12	1.12	95	.92	.80	2.4	3.8	6.1	5.4	8.3	13.2	1.6
6 **ALMENDRO** Caryocar coccineum CARYOCARACEAE	PE	79	11	1.16	.79	.75	.65	2.5	6.5	8.9	4.4	9.6	13.6	2.2
7 **APAMATE** Tabebuia rosea BIGNONIACEAE	VE	75	14	.95	65	.61	.54	1.9	2.9	4.8	4.6	6.9	11.1	1.5

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm³	DSA g/cm³	DA g/cm³	DB g/cm³	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
8 **BARAMAN** *Catostemma commune* BOMBACACEAE	VE	71	14	86	63	.60	.50	2.9	6.0	8.6	5.8	10.9	16.1	2.0
9 **BIBOSI** *Ficus glabrata* MORACEAE	BO	95	12	.97	59	56	.50	1.6	3.8	5.4	3.6	7.5	10.8	2.1
10 **BLANQUILLO** *Buchenavia exicarpa* COMBRETACEAE	BO	44	12	1.11	.93	90	.77	2.4	5.1	7.4	5.1	10.3	14.8	2.0
11 **BONGA** *Ceiba pentandra* BOMBACACEAE	CO	132	18	.47	.25	.22	.21	.8	1.7	2.5	2.3	4.1	6.2	1.9
12 **CACHIMBO** *Cariniana domesticaca* LECYTHIDACEAE	PE	61	14	.95	.72	.67	.59	2.1	3.6	5.6	4.9	7.5	12.0	1.5
13 **CAIMITILLO** *Chrysophyllum cainito* SAPOTACEAE	EC	64	13	1.21	.94	91	.74	4.7	7.2	11.6	7.9	11.1	18.2	1.5
14 **CAIMITO COLORADO** *Pouteria sp.* SAPOTACEAE	CO	47	14	1.00	.84	.80	.68	2.8	4.6	7.3	6.3	9.2	14.9	1.5

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm^3	DSA g/cm^3	DA g/cm^3	DB g/cm^3	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
15 CANIME *Copaifera sp.* CAESALPINIACEAE	CO	40	16	.68	.57	.53	.48	1.3	1.9	3.1	3.7	5.1	8.6	1.5
16 CARACOLI *Anacardium excelsum* ANACARDIACEAE	CO	74	16	.59	.40	.37	.34	.8	1.4	2.1	2.7	4.4	7.0	1.7
17 CARAPA *Carapa guianensis* MELIACEAE	VE	59	14	.88	.68	.64	.55	1.9	3.9	5.7	4.7	8.2	12.6	1.8
18 CARBONERO *Licania campestre* ROSACEAE	CO	58	17	.94	.74	.70	.59	2.3	4.4	6.6	6.1	9.5	15.0	1.6
19 CARNE ASADA *Hieronyma laxiflora* EUPHORBIACEAE	VE	66	14	.92	.69	.65	.55	2.5	4.8	7.3	5.1	8.8	13.4	1.8
20 CARRA *Huberodendron patinoi* BOMBACACEAE	CO	96	11	.99	.63	.59	.50	3.1	5.5	8.5	5.7	8.7	13.9	1.5
21 CASHO MOENA *Ocotea sp.* LAURACEAE	PE	75	11	.92	.63	.60	.53	2.6	6.7	9.2	3.7	8.7	12.1	2.4

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm³	DSA g/cm³	DA g/cm³	DB g/cm³	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
22 CATAHUA AMARILLA *Hura crepitans* EUPHORBIACEAE	PE	61	14	66	49	46	.41	1.4	2.7	4.0	3.5	5.8	9.1	1.7
23 CHANUL *Humiriastrum procerum* HUMIRIACEAE	EC	68	12	1.12	.83	.80	.66	4.4	6.6	10.6	7.1	10.0	16.5	1.4
24 CHANUL *Humiriastrum procerum* HUMIRIACEAE	CO	57	15	1.08	87	.84	.69	3.6	5.8	9.2	7.4	11.1	17.7	1.5
25 CHAQUIRO *Goupia glabra* CELASTRACEAE	CO	64	12	1.12	.82	79	.68	2.6	4.4	6.9	5.4	8.5	13.5	1.6
26 CHARO AMARILLO *Brosimum alicastrum ssp. bolivarensis* MORACEAE	VE	68	14	1.09	.79	.74	.65	2.1	3.6	5.7	4.9	7.9	12.4	1.6
27 CHIMI *Pseudolmedia laevigata* MORACEAE	EC	85	12	1.15	.79	.75	.62	3.2	7.7	10.7	5.5	11.4	16.2	2.1
28 CHIMICUA *Pseudolmedia laevis* MORACEAE	PE	39	13	.98	.86	.82	.70	2.1	5.9	7.8	4.8	10.3	14.6	2.2

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm^3	DSA g/cm^3	DA g/cm^3	DB g/cm^3	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
29 CHUPON ROSADO *Pouteria anibifolia* SAPOTACEAE	VE	70	13	1.13	.81	.77	.66	2.4	4.9	7.2	5.1	9.1	13.8	1.8
30 COCUELO BLANCO *Gustavia speciosa* LECYTHIDACEAE	CO	75	16	.60	.42	.38	.34	1.5	2.3	3.8	3.6	4.9	8.4	1.4
31 COPAIBA *Copaifera officinalis* CAESALPINIACEAE	PE	55	15	.93	.73	.68	.60	1.3	3.2	4.4	3.4	7.0	10.2	2.1
32 COQUINO *Ardisia cubana* MYRSINACEAE	BO	70	12	1.05	.76	.73	.62	2.6	6.3	8.7	4.6	10.4	14.5	2.3
33 CUANGARE *Dialyanthera gracilipes* MYRISTICACEAE	CO	114	13	.69	.40	.38	.32	2.2	6.1	8.1	4.3	9.7	13.6	2.3
34 CURUPAU *Piptadenia grata* MIMOSACEAE	BO	40	13	1.20	1.03	.98	.86	1.7	3.5	5.2	3.8	8.3	11.8	2.2
35 DIABLO FUERTE *Podocarpus sp.* PODOCARPACEAE	PE	115	14	1.13	.63	.58	.53	1.5	3.3	4.7	3.2	6.1	9.1	1.9

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm³	DSA g/cm³	DA g/cm³	DB g/cm³	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
36 DORMILON *Pentaclethra macroloba* MIMOSACEAE	CO	130	13	.99	.53	.50	.43	1.9	5.8	7.5	3.9	9.8	13.3	2.6
37 ESTORAQUE *Myroxylon peruiferum* PAPILIONACEAE	PE	30	11	1.01	.91	.86	.78	2.0	3.6	5.5	4.2	6.5	10.4	1.6
38 EUCALIPTO *Eucalyptus globulus* MYRTACEAE	EC	111	12	1.16	.73	.70	.55	4.4	10.8	14.7	6.7	14.2	19.9	2.2
39 FERNANSANCHEZ *Triplaris guayaquilensis* POLYGONACEA	EC	84	12	.97	.63	.60	.53	2.3	4.8	7.0	4.3	8.0	12.0	1.8
40 GUAYABOCHI *Calycophyllum spruceanum* RUBIACEAE	BO	45	13	1.07	.90	.86	.74	2.4	4.5	6.8	5.0	9.2	13.7	1.9
41 GUAYABON *Terminalia guianensis* COMBRETACEAE	VE	64	14	1.04	.77	.72	.64	1.8	3.5	5.2	4.5	7.7	11.9	1.7
42 GUAYACAN PECHICHE *Minquartia guianensis* OLACCACEAE	EC	61	12	1.22	.88	.86	.76	1.2	2.2	4.3	4.2	8.2	12.1	2.0

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm³	DSA g/cm³	DA g/cm³	DB g/cm³	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
43 **HOBO COLORADO** *Spondias mombin* ANACARDIACEAE	CO	85	16	.57	.37	.34	.31	1.2	2.2	3.4	3.1	5.1	8.0	1.7
44 **HUAYRURO** *Ormosia coccinea* PAPILIONACEAE	PE	74	13	1.04	.70	.66	.60	1.1	2.4	3.5	3.2	6.4	9.3	2.1
45 **HUIMBA** *Ceiba samauma* BOMBACACEAE	PE	86	15	1.04	.68	.63	.56	1.8	3.7	5.4	4.1	7.5	11.3	1.9
46 **JIBARO** *Pithecellobium latifolium* MIMOSACEAE	EC	140	12	.85	.43	.40	.36	2.5	4.6	7.0	4.1	7.2	11.0	1.8
47 **KAQUI** *Diospyros sp.* EBENACEAE	BO	89	12	.90	.60	.56	.47	3.2	7.8	10.7	5.3	11.6	16.3	2.2
48 **LAGUNO** *Vochysia macrophylla* VOCHYSIACEAE	EC	181	12	1.01	.45	.43	.36	3.0	7.5	10.3	4.6	10.2	14.3	2.6
49 **MACHARE** *Symphonia globulifera* GUTTIFERAE	CO	73	13	1.01	.72	.69	.58	2.6	6.2	8.7	5.3	11.3	16.0	2.2

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV - g/cm³	DSA g/cm³	DA g/cm³	DB g/cm³	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
50 **MANCHINGA** Brosimum uleanum MORACEAE	PE	44	14	.98	.81	.77	.68	1.8	3.3	5.0	5.0	8.1	12.7	1.6
51 **MAPAJO** Ceiba pentandra BOMBACACEAE	BO	83	12	.95	.63	.60	.52	2.3	4.7	6.9	4.5	8.2	12.4	1.8
52 **MAQUIZAPA ÑAGCHA** Apeiba aspera TILIACEAE	PE	80	15	.54	.37	.33	.30	.7	2.5	3.2	2.3	6.3	8.4	2.9
53 **MARUPA** Simarouba amara SIMAROUBACEAE	PE	61	14	.58	.43	.39	.36	1.3	3.8	5.0	2.9	6.7	9.4	2.4
54 **MASCAREY** Hieronyma chocoensis EUPHORBIACEAE	EC	85	12	1.08	.77	.74	.59	4.3	10.4	14.2	6.4	13.6	19.1	2.2
55 **MIJAO** Anacardium excelsum ANACARDIACEAE	VE	109	13	.74	.42	.38	.35	1.0	2.2	3.2	2.7	5.1	7.7	2.0
56 **MOENA NEGRA** Nectandra sp. LAURACEAE	PE	60	18	.67	.50	.45	.41	.6	1.7	2.3	2.7	5.9	8.4	2.3

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm³	DSA g/cm³	DA g/cm³	DB g/cm³	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
57 **MORA** *Clarisia racemosa* MORACEAE	CO	92	14	.88	.54	.49	.46	.7	1.5	2.1	2.6	4.9	7.4	2.0
58 **MORA** *Mora gonggrijpii* CAESALPINIACEAE	VE	49	13	1.16	.98	.93	.78	3.1	4.8	7.8	6.3	9.7	15.4	1.5
59 **MORAL FINO** *Chlorophora tinctoria* MORACEAE	EC	66	12	1.18	.81	.76	.71	.9	1.6	2.5	2.3	3.9	6.1	1.9
60 **MUREILLO** *Erisma uncinatum* VOCHYSIACEAE	VE	105	15	.97	.58	.54	.47	1.9	4.6	6.4	4.2	9.1	12.9	2.2
61 **MURURE** *Clarisia racemosa* MORACEAE	BO	77	11	1.10	.71	.67	.62	1.1	2.0	3.1	2.6	4.9	7.4	2.0
62 **NATO** *Mora megistosperma* CAESALPINIACEAE	CO	85	11	1.17	.77	.74	.63	2.8	5.6	8.2	5.0	9.3	13.8	1.9
63 **NEGRILLO** *Persea caurulea* LAURACEAE	BO	71	11	.73	.50	.47	.42	2.2	3.9	6.0	3.9	6.6	10.3	1.7

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm^3	DSA g/cm^3	DA g/cm^3	DB g/cm^3	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
64 OCHOO Hura crepitans EUPHORBIACEAE	BO		11	.68	.50	.47	.42	1.9	3.1	5.0	3.6	5.4	8.8	1.5
65 OLOROSO Humiria balsamifera HUMIRIACEAE	CO	50	14	1.02	.89	.87	.68	4.6	8.1	12.3	8.	13.1	20.2	1.7
66 PACAY Inga edulis MIMOSACEAE	BO	78	12	.90	.61	.58	.51	2.0	4.6	6.5	3.8	8.2	11.7	2.2
67 PACORA Cespedesia spathulata OCHNACEAE	EC	113	12	1.15	.72	.68	.54	4.7	10.8	15.0	7.3	14.0	20.3	2.0
68 PALO MARIA Calophyllum brasiliense GUTTIFERAE	BO	73	12	.95	.66	.63	.56	2.6	5.0	7.5	5.0	8.4	13.0	1.7
69 PALOSANGRE AMARILLO Pterocarpus sp. PAPILIONACEAE	PE	45	13	1.02	.87	.84	.71	2.7	5.7	8.2	5.6	10.1	15.1	1.9
70 PALO SANGRE NEGRO Pterocarpus sp. PAPILIONACEAE	PE	61	13	1.17	.83	.78	.72	.7	1.3	2.1	2.7	4.8	7.4	1.9

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm^3	DSA g/cm^3	DA g/cm^3	DB g/cm^3	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
71 PANGUANA *Brosimum utile* MORACEAE	PE	62	15	.77	.58	.53	.48	1.2	2.9	4.0	3.7	6.9	10.4	1.9
72 PANTANO *Hieronyma chocoensis* EUPHORBIACEAE	CO	81	15	1.13	.79	.74	.62	2.6	6.4	8.8	5.6	10.8	15.9	2.0
73 PARDILLO AMARILLO *Terminalia amazonia* COMBRETACEAE	VE	65	14	1.07	.78	.73	.65	2.0	3.4	5.3	4.6	7.3	11.6	1.6
74 PERHUETAMO *Mouriri barinensis* MELASTOMATACEAE	VE	53	14	1.19	.97	.93	.78	2.2	5.1	7.1	5.6	11.2	16.1	2.0
75 PIASTE *Guarea sp.* MELIACEAE	EC	157	12	1.12	.53	.49	.43	2.5	5.2	7.6	4.1	8.0	11.8	2.0
76 PINO INSIGNE *Pinus radiata* PINACEAE	EC	163	12	1.04	.48	.45	.39	3.0	5.2	8.0	4.6	7.7	11.9	1.7
77 PITUCA *Clarisia racemosa* MORACEAE	EC	113	12	1.09	.61	.57	.51	1.4	3.0	4.4	2.8	5.8	8.4	2.1

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm^3	DSA g/cm^3	DA g/cm^3	DB g/cm^3	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
78 PLUMERO *Vochysia lanceolata* VOCHYSIACEAE	BO	104	12	1.00	.60	.57	.49	2.3	6.8	8.9	4.0	10.6	14.1	2.8
79 PUMAQUIRO *Aspidosperma macrocarpon* APOCYNACEAE	PE	68	12	1.11	.80	.76	.67	2.0	4.7	6.6	4.1	8.0	11.8	2.1
80 PUNULA *Quararibea asterolepsis* BOMBACACEAE	CO	51	15	.68	.54	.50	.45	1.6	3.2	4.7	3.9	7.1	10.7	1.9
81 ROMERILLO AZUCENO *Podocarpus oleifolius* PODOCARPACEAE	EC	102	12	.89	.53	.51	.44	2.4	4.3	6.5	4.9	8.0	12.5	1.7
82 ROMERILLO FINO *Podocarpus rospigliosii* PODOCARPACEAE	EC	59	12	.91	.68	.64	.57	1.6	3.2	4.8	3.2	5.7	8.7	1.9
83 SAJO *Campnosperma panamensis* ANACARDIACEAE	CO	162	14	.99	.47	.44	.37	3.0	5.4	8.2	5.6	8.8	13.9	1.6
84 SAMAN *Pithecellobium saman* MIMOSACEAE	VE	132	13	1.13	.57	.53	.49	10.1	2.0	3.1	3.0	5.1	7.9	1.8

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm³	DSA g/cm³	DA g/cm³	DB g/cm³	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
85 **SANDE** Brosimum utile MORACEAE	CO	75	12	.74	.50	.47	.42	1.9	3.9	5.7	4.1	7.3	11.1	1.8
86 **SANDE** Brosimum utile MORACEAE	EC	152	12	1.02	.49	.46	.40	2.1	5.3	7.3	3.8	8.3	11.8	2.3
87 **SANGRE DE GRADO** Pterocarpus vernalis PAPILIONACEAE	VE	79	14	1.03	.69	.64	.57	1.7	3.2	4.9	3.7	6.9	10.3	1.8
88 **SANGRE DE VACA** Licania sp. ROSACEAE	BO	78	12	1.00	.68	.66	.56	2.6	5.5	8.0	4.9	9.5	13.9	2.0
89 **SAQUI SAQUI** Bombacopsis quinata BOMBACACEAE	VE	116	14	.85	.46	.43	.39	.9	1.9	2.8	3.0	5.1	8.0	1.7
90 **SEBO** Virola reidii MYRISTICACEAE	CO	110	12	.75	.44	.42	.35	3.1	6.7	9.7	5.6	10.5	15.5	1.9
91 **SEIQUE** Cedrelinga catenaeformis MIMOSACEAE	EC	105	12	.75	.45	.42	.37	2.5	5.4	7.7	4.1	8.3	12.0	2.1

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm^3	DSA g/cm^3	DA g/cm^3	DB g/cm^3	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
92 SEREBO *Schyzolobium parahybum* CAESALPINIACEAE	BO	83	13	.74	.44	.41	.40	1.7	3.7	5.3	3.7	7.0	10.4	1.9
93 SOROGA *Vochysia ferruginea* VOCHYSIACEAE	CO	163	13	.98	.46	.43	.37	2.1	6.6	8.5	4.0	10.3	13.9	2.9
94 SUN SUN *Didymopanax morototoni* ARALIACEAE	VE	91	14	.69	.45	.42	.36	2.6	4.6	7.0	5.3	8.3	13.1	1.6
95 TACHORE *Poulsenia armata* MORACEAE	BO	105	12	.76	.44	.41	.37	2.2	4.5	6.5	4.0	7.3	11.0	1.8
96 TANGAMA *Parkia sp.* MIMOSACEAE	EC	221	12	1.00	.40	.38	.33	2.2	5.1	7.2	3.7	7.9	11.4	2.5
97 TANGARE *Carapa guianensis* MELIACEAE	CO	78	15	.87	.60	.56	.49	1.9	4.2	6.0	4.7	8.6	12.9	1.9
98 TORNILLO *Cedrelinga catenaeformis* MIMOSACEAE	PE	83	15	.82	.55	.50	.44	1.0	3.0	3.9	3.2	6.9	9.9	2.2

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	CHV o/o	CHSA o/o	DV g/cm^3	DSA g/cm^3	DA g/cm^3	DB g/cm^3	CRN o/o	CTN o/o	CVN o/o	CRT o/o	CTT o/o	CVT o/o	T/R o/o
99 UCSHAQUIRO BLANCO *Sclerolobium sp.* CAESALPINIACEAE	PE	64	14	.64	.46	.42	.38	1.3	3.0	4.2	3.4	6.6	9.8	2.0
100 VERDOLAGO *Terminalia amazonia* COMBRETACEAE	BO	56	12	1.01	.79	.76	.65	3.1	5.5	8.4	5.5	9.2	14.1	1.7
101 VIROLA *Virola sebifera* MYRISTICACEAE	VE	141	13	.89	.46	.44	.37	2.1	7.9	9.8	4.5	11.5	15.5	2.7
102 YESQUERO *Cariniana estrellensis* LECYTHIDACEAE	BO	69	12	.96	.68	.64	.57	2.3	4.4	6.6	4.4	7.4	11.5	1.7
103 YUMBINGUE *Terminalia guianensis* COMBRETACEAE	EC	79	12	1.08	.74	.70	.61	3.0	5.5	8.4	5.1	8.6	13.3	1.7
104 ZAPATERO *Peltogyne porphyrocardia* CAESALPINIACEAE	VE	42	14	1.26	1.06	1.01	.89	1.4	2.4	3.8	4.3	7.3	11.3	1.7

APPENDIX B

MEAN MECHANICAL PROPERTIES OF THE WOOD OF 104 SPECIES OF THE ANDEAN GROUP

Translations and Abbreviations

flexion estatica	:	static bending
ELP	:	stress at proportional limit
MOR	:	modulus of rupture
MOE	:	modulus of elasticity
compresion paral.	:	compression parallel to grain
ER	:	maximum crushing stress
compresion perp.	:	compression perpendicular to grain
ELP	:	stress at proportional limit
cizallamiento	:	shear
radial	:	radial
tan	:	tangential
dureza	:	hardness
lados	:	side penetration
extre	:	end penetration
tenacidad	:	toughness

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	COMPRESION PERP.	CIZALLAMIENTO RADIAL	CIZALLAMIENTO TAN.	DUREZA LADOS	DUREZA EXTRE.	TENACIDAD RADIAL	TENACIDAD TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
1 ACEITE CABIMO *Copaifera pubiflora* CAESALPINIACEAE	VE	.56	Verde	446	802	116	360	44	72	32	466	472	1.71	1.83
			Seco12	616	1124	118	631	80	141	154	860	876	1.61	1.81
2 ACEITE MARIO *Calophyllum mariae* GUTTIFERAE	CO	.46	Verde	407	652	114	303	42	63	70	324	396	2.63	2.79
			Seco12	804	1179	164	658	84	91	102	464	686	3.76	3.52
3 AJO AJO *Gallesia integrifolia* PHYTOLACCACEAE	BO	.51	Verde	317	436	60	244	59	58	42	381	343	1.63	1.75
			Seco12	444	659	98	380	70	75	69	403	521	1.33	1.58
4 ALGARROBO *Hymenaea courbaril* CAESALPINIACEAE	VE	.77	Verde	603	1069	138	391	80	137	154	804	780	2.20	2.62
			Seco12	816	1515	163	686	117	186	210	1361	1517	2.06	2.16
5 ALMENDRILLO *Taralea oppositifolia* PAPILIONACEAE	BO	.80	Verde	866	1092	141	628	153	141	151	1117	1043	4.38	5.09
			Seco12	779	1067	151	884	201	173	178	1628	1581	4.23	5.65
6 ALMENDRO *Caryocar coccineum* CARYOCARACEAE	PE	.65	Verde	450	713	146	332	67	88	102	606	504	3.75	3.53
			Seco12	356	615	86	441	91	108	115	620	577	3.34	3.33
7 APAMATE *Tabebuia rosea* BIGNONIACEAE	VE	.54	Verde	404	837	125	386	42	91	84	427	513	2.06	2.13
			Seco12	587	1104	124	635	66	141	125	562	761	1.50	1.70

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	PERP.	CIZALLAMIENTO RADIAL	TAN.	DUREZA LADOS	EXTRE.	TENACIDAD RADIAL	TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg - m	kg - m
8 **BARAMAN** Catostemma commune BOMBACACEAE	VE	.50	Verde	383	647	122	258	23	49	52	259	276	96	1.15
			Seco 12	518	868	137	527	45	88	71	359	471	1.19	1.33
9 **BIBOSI** Ficus glabrata MORACEAE	BO	.50	Verde	345	502	73	242	53	62	70	302	311	1.00	1.36
			Seco 12	305	475	72	393	76	74	84	323	480	1.03	1.39
10 **BLANQUILLO** Buchenavia oxicarpa COMBRETACEAE	BO	.77	Verde	644	946	113	457	118	104	135	909	881	5.28	6.20
			Seco 12	772	1355	164	644	162	133	156	1417	1459	3.52	3.98
11 **BONGA** Ceiba pentandra BOMBACACEAE	CO	.21	Verde	123	181	27	95	8	24	29	74	101	1.22	1.34
			Seco 12	241	319	40	190	22	35	35	118	195	96	1.14
12 **CACHIMBO** Cariniana domesticata LECYTHIDACEAE	PE	.59	Verde	416	716	132	343	64	85	85	467	447	4.03	3.83
			Seco 12	626	1134	164	521	97	122	113	638	522	4.80	4.47
13 **CAIMITILLO** Chrysophyllum cainito SAPOTACEAE	EC	.74	Verde	535	1006	175	459	68	89		669	698	2.94	
			Seco 12	780	1535	196	910	99	110		1083	1113	4.76	
14 **CAIMITO COLORADO** Pouteria sp. SAPOTACEAE	CO	.68	Verde	699	1000	136	448	75	94	96	620	679		
			Seco 12	988	1378	162	596	142	136	159	841	969	5.41	6.09

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION		CIZALLAMIENTO		DUREZA		TENACIDAD	
							PARAL.	PERP.	RADIAL	TAN.	LADOS	EXTRE.	RADIAL	TAN
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg - m	kg - m
15 CANIME Copaifera sp. CAESALPINIACEAE	CO	.48	Verde	311	637	77	306	55	76	88	376	403	4.12	4.07
			Seco 12	584	872	98	426	87	117	130	432	531	3.85	3.09
16 CARACOLI Anacardium excelsum ANACARDIACEAE	CO	.34	Verde	230	378	58	177	20	44	50	146	213	1.59	1.37
			Seco 12	389	524	72	278	48	80	61	187	288	1.26	1.19
17 CARAPA Carapa guianensis MELIACEAE	VE	.66	Verde	385	722	124	372	32	70	91	420	488	1.58	1.46
			Seco 12	612	1029	136	680	60	117	157	584	758	1.65	1.61
18 CARBONERO Licania campestre ROSACEAE	CO	.59	Verde	485	786	113	330	45	70	88	392	450	4.09	4.09
			Seco 12	780	1118	143	566	101	102	132	620	681	4.67	4.16
19 CARNE ASADA Hieronyma laxiflora EUPHORBIACEAE	VE	.55	Verde	254	600	106	293	34	68	81	356	439	1.76	1.93
			Seco 12	709	1068	121	522	71	120	137	508	685	.87	.99
20 CARRA Huberodendron patinoi BOMBACACEAE	CO	.60	Verde	439	773	117	360	50	56	72	312	386	1.66	1.65
			Seco 12	963	1208	157	887	57	68	73	390	583	2.22	2.11
21 CASHO MOENA Ocotea sp. LAURACEAE	PE	.53	Verde	379	581	118	320	47	66	87	364	333	3.01	2.95
			Seco 12	404	721	118	408	61	83	98	405	390	2.38	2.14

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	PERP.	CIZALLAMIENTO RADIAL	TAN.	DUREZA LADOS	EXTRE.	TENACIDAD RADIAL	TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
22 CATAHUA AMARILLA *Hura crepitans* EUPHORBIACEAE	PE	.41	Verde	228	402	70	184	28	46	52	230	225	2.07	2.01
			Seco 12	398	725	101	397	68	80	91	356	445	2.20	2.43
23 CHANUL *Humiriastrum procerum* HUMIRIACEAE	EC	.66	Verde	526	963	143	428	60	88		557	609	3.42	
			Seco 12	687	1354	174	694	94	146		753	883	3.47	
24 CHANUL *Humiriastrum procerum* HUMIRIACEAE	CO	.69	Verde	550	861	141	471	78	95	110	547	654	3.49	3.14
			Seco 12	932	1472	180	733	149	93	129	705	897	4.17	3.68
25 CHAQUIRO *Goupia glabra* CELASTRACEAE	CO	.68	Verde	667	1011	137	512	103	112	96	614	635	3.55	3.67
			Seco 12	816	1294	152	661	134	71	96	637	735	2.66	2.93
26 CHARO AMARILLO *Brosimum alicastrum* ssp. *bolivarensis* MORACEAE	VE	.65	Verde	413	786	105	448	88	99	128	634	708	2.43	2.57
			Seco 12	792	1326	142	725	135	151	172	867	1107	1.86	1.74
27 CHIMI *Pseudolmedia laevigata* MORACEAE	EC	.62	Verde	413	764	103	382	62	88		518	579	3.50	
			Seco 12	659	1192	145	619	77	133		660	801	4.07	
28 CHIMICUA *Pseudolmedia laevis* MORACEAE	PE	.70	Verde	547	906	161	453	74	93	124	762	734	3.81	3.88
			Seco 12	727	1278	174	658	142	140	183	998	1033	4.10	4.14

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION		CIZALLAMIENTO		DUREZA		TENACIDAD	
							PARAL.	PERP.	RADIAL	TAN.	LADOS	EXTRE.	RADIAL	TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
29 CHUPON ROSADO *Pouteria anibifolia* SAPOTACEAE	VE	.66	Verde	341	733	119	346	58	91	115	553	663	2.05	2.07
			Seco 12	630	1312	150	648	100	130	152	834	1007	1.62	1.64
30 COCUELO BLANCO *Gustavia speciosa* LECYTHIDACEAE	CO	.34	Verde	251	406	54	181	21	45	51	234	311	2.99	2.13
			Seco 12	418	586	72	322	48	67	70	207	325	1.73	1.50
31 COPAIBA *Copaifera officinalis* CAESALPINIACEAE	PE	.60	Verde	425	731	110	359	72	89	110	587	528	3.59	3.30
			Seco 12	550	930	123	523	114	114	140	617	769	2.49	2.62
32 COQUINO *Ardisia cubana* MYRSINACEAE	BO	.62	Verde	490	739	88	349	77	89	104	563	556	3.85	4.07
			Seco 12	558	1013	125	545	108	104	129	833	1005	4.65	3.95
33 CUANGARE *Dialyanthera gracilipes* MYRISTICACEAE	CO	.32	Verde	261	503	86	189	24	33	55	117	167	.94	.88
			Seco 12	396	636	105	399	45	39	70	209	340	1.77	1.65
34 CURUPAU *Piptadenia grata* MIMOSACEAE	BO	.86	Verde	839	1175	149	564	157	144	166	1200	1020	5.99	6.42
			Seco 12	896	1672	192	839	231	163	173	1990	1878	6.46	7.47
35 DIABLO FUERTE *Podocarpus sp.* PODOCARPACEAE	PE	.53	Verde	366	608	99	302	57	78	99	425	365	2.80	2.84
			Seco 12	583	904	115	492	93	115	144	509	645	1.84	1.85

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CON-DI-CION	FLEXION ESTATICA			COMPRESION PARAL.	COMPRESION PERP.	CIZALLAMIENTO RADIAL	CIZALLAMIENTO TAN.	DUREZA LADOS	DUREZA EXTRE.	TENACIDAD RADIAL	TENACIDAD TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
36 DORMILON *Pentaclethra macroloba* MIMOSACEAE	CO	.43	Verde	416	655	96	335	67	68	79	354	411	1.76	1.66
			Seco 12	641	935	127	493	90	85	96	359	583	1.95	2.26
37 ESTORAQUE *Myroxylon peruiferum* PAPILIONACEAE	PE	.78	Verde	853	1299	167	700	114	148	148	1187	1144	6.56	6.60
			Seco 12	976	1648	186	783	186	173	192	1279	1280	6.63	6.23
38 EUCALIPTO *Eucalyptus globulus* MYRTACEAE	EC	.55	Verde	383	702	104	288	58	97		478	480	4.81	
			Seco 12	509	1068	138	470	80	117		442	557	3.45	
39 FERNANSANCHEZ *Triplaris guayaquilensis* POLYGONACEAE	EC	.53	Verde	344	719	111	334	58	92		411	465	2.28	
			Seco 12	489	1019	128	516	82	108		484	667	2.64	
40 GUAYABOCHI *Calycophyllum spruceanum* RUBIACEAE	BO	.74	Verde	683	1028	108	500	131	124	159	979	865	5.66	6.00
			Seco 12	813	1312	162	660	183	141	178	1374	1486	4.17	4.68
41 GUAYABON *Terminalia guianensis* COMBRETACEAE	VE	.64	Verde	393	771	113	437	66	102	110	534	651	2.03	2.30
			Seco 12	678	1246	127	608	106	146	149	802	1027	1.94	2.25
42 GUAYACAN PECHICHE *Minquartia guianensis* OLACCACEAE	EC	.76	Verde	544	906	132	441	99	94		587	533	5.39	
			Seco 12	753	1586	171	710	84	97		811	720	3.31	

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS.	CON-DI-CION	FLEXION ESTATICA			COMPRESION		CIZALLAMIENTO		DUREZA		TENACIDAD	
							PARAL.	PERP.	RADIAL	TAN.	LADOS	EXTRE.	RADIAL	TAN.
		g/cm³		ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
43 HOBO COLORADO Spondias mombin ANACARDIACEAE	CO	.31	Verde	232	367	60	160	14	44	53	141	214	1.61	1.46
			Seco 12	355	487	73	295	38	59	61	142	270	1.15	1.19
44 HUAYRURO Ormosia coccinea PAPILIONACEAE	PE	.60	Verde	529	843	134	443	70	98	113	661	611	3.67	3.73
			Seco 12	706	1095	148	592	84	138	114	706	732	3.97	3.60
45 HUIMBA Ceiba samauma BOMBACACEAE	PE	.56	Verde	383	582	105	287	40	63	74	360	365	2.33	2.07
			Seco 12	416	629	108	380	73	77	94	384	468	1.95	1.87
46 JIBARO Pithecellobium latifolium MIMOSACEAE	EC	.36	Verde	210	402	58	217	33	65		227	303	1.90	
			Seco 12	328	698	92	339	37	77		241	376	2.10	
47 KAQUI Diospyros sp. EBENACEAE	BO	.47	Verde	325	483	70	228	42	60	77	294	308	1.45	1.17
			Seco 12	485	785	109	472	88	77	90	457	622	1.12	1.12
48 LAGUNO Vochysia macrophylla VOCHYSIACEAE	EC	.36	Verde	195	421	73	180	26	44		185	239	1.75	
			Seco 12	362	725	98	365	45	68		235	375	2.34	
49 MACHARE Symphonia globulifera GUTTIFERAE	CO	.58	Verde	697	1023	141	495	80	74	94	494	544	2.57	2.59
			Seco 12	837	1408	165	708	97	78	92	587	765	3.58	3.42

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	PERP.	CIZALLAMIENTO RADIAL	TAN.	DUREZA LADOS	EXTRE.	TENACIDAD RADIAL	TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
50 MANCHINGA Brosimum uleanum MORACEAE	PE	.68	Verde	465	782	117	367	78	95	119	714	705	3.77	3.53
			Seco 12	598	1044	140	531	128	147	166	777	922	2.85	2.64
51 MAPAJO Ceiba pentandra BOMBACACEAE	BO	.62	Verde	402	570	85	291	54	62	73	362	371	1.46	1.81
			Seco 12	500	798	107	435	73	80	87	396	658	1.69	1.88
52 MAQUIZAPA ÑAGCHA Apeiba aspera TILIACEAE	PE	.30	Verde	163	279	53	159	9	46	32	157	173	1.35	1.36
			Seco 12	315	504	73	308	40	45	42	172	249	1.33	1.49
53 MARUPA Simarouba amara SIMAROUBACEAE	PE	.36	Verde	258	427	77	201	33	51	64	204	227	1.63	1.58
			Seco 12	337	534	85	312	41	67	73	206	328	1.31	1.46
54 MASCAREY Hieronyma chocoensis EUPHORBIACEAE	EC	.59	Verde	321	723	113	309	41	71		405	444	2.16	
			Seco 12	631	1354	148	679	76	124		667	1017	2.83	
55 MIJAO Anacardium excelsum ANACARDIACEAE	VE	.35	Verde	194	369	68	160	21	41	49	134	188	.61	.66
			Seco 12	337	531	82	311	29	58	62	174	260	.44	.50
56 MOENA NEGRA Nectandra sp. LAURACEAE	PE	.41	Verde	309	539	93	270	49	69	77	291	282	2.32	2.27
			Seco 12	530	779	110	355		70	62			2.24	2.12

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	PERP.	CIZALLAMIENTO RADIAL	TAN.	DUREZA LADOS	EXTRE.	TENACIDAD RADIAL	TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
57 **MORA** Clarisia racemosa MORACEAE	CO	.46	Verde	501	715	93	357	54	80	86	386	446	2.83	2.86
			Seco 12	767	922	117	523	82	99	99	353	480	2.27	3.17
58 **MORA** Mora gonggrijpii CAESALPINIACEAE	VE	.78	Verde	634	1103	158	528	67	116	141	800	789	2.86	2.88
			Seco 12	959	1805	211	872	119	154	158	1246	1298	3.35	3.22
59 **MORAL FINO** Chlorophora tinctoria MORACEAE	EC	.71	Verde	678	1074	124	542	104	112		899	844	2.68	
			Seco 12	848	1407	152	819	111	109		752	1406	3.56	
60 **MUREILLO** Erisma uncinatum VOCHYSIACEAE	VE	.47	Verde	330	644	121	254	32	66	61	283	354	1.09	1.27
			Seco 12	495	897	115	524	54	98	86	374	576	1.03	1.12
61 **MURURE** Clarisia racemosa MORACEAE	BO	.62	Verde	694	940	117	497	98	94	106	640	641	3.07	2.94
			Seco 12	614	985	123	784	137	126	128	893	985	2.58	2.97
62 **NATO** Mora megistosperma CAESALPINIACEAE	CO	.63	Verde	486	820	124	383	92	93	88	595	608	3.24	4.14
			Seco 12	677	1261	156	606	85	88	95	585	707	3.79	4.29
63 **NEGRILLO** Persea caerulea LAURACEAE	BO	.42	Verde	391	583	82	288	50	64	83	305	338	2.64	2.54
			Seco 12	454	755	110	473	69	77	81	475	603	2.26	2.34

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	COMPRESION PERP.	CIZALLAMIENTO RADIAL	CIZALLAMIENTO TAN.	DUREZA LADOS	DUREZA EXTRE.	TENACIDAD RADIAL	TENACIDAD TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg - m	kg - m
64 OCHOO *Hura crepitans* EUPHORBIACEAE	BO	.42	Verde	354	489	66	259	52	61	66	241	265	1.92	1.72
			Seco 12	390	685	99	445	70	81	84	364	523	1.88	2.09
65 OLOROSO *Humiria balsamifera* HUMIRIACEAE	CO	.68	Verde	565	986	148	371	96	90	104	608	637	3.59	3.32
			Seco 12	1150	1730	195	865	181	127	171	940	1341	3.59	3.51
66 PACAY *Inga edulis* MIMOSACEAE	BO	.51	Verde	449	676	90	297	60	85	90	474	497	1.78	1.90
			Seco 12	555	876	114	505	91	93	108	501	688	1.74	1.94
67 PACORA *Cespedesia spathulata* OCHNACEAE	EC	.54	Verde	239	575	93	242	36	77		372	411	3.06	
			Seco 12	452	1010	125	475	58	132		494	677	2.78	
68 PALO MARIA *Calophyllum brasiliense* GUTTIFERAE	BO	.55	Verde	487	683	92	343	60	83	96	482	502	2.67	3.44
			Seco 12	659	913	130	579	94	99	115	743	871	3.33	3.06
69 PALO SANGRE AMARILLO *Pterocarpus* sp. PAPILIONACEAE	PE	.71	Verde	.547	889	156	445	75	98	122	863	765	5.10	5.08
			Seco 12	645	1056	165	656	124	157	152	851	922	4.04	3.60
70 PALO SANGRE NEGRO *Pterocarpus* sp. PAPILIONACEAE	PE	.72	Verde	648	1050	138	516	93	119	132	1025	910	5.93	5.38
			Seco 12	913	1489	188	756	170	220	156	1090	1250	5.30	4.58

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	COMPRESION PERP.	CIZALLAMIENTO RADIAL	CIZALLAMIENTO TAN.	DUREZA LADOS	DUREZA EXTRE.	TENACIDAD RADIAL	TENACIDAD TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
71 PANGUANA Brosimum utile MORACEAE	PE	.48	Verde	284	514	102	265	41	71	78	390	361	2.81	2.66
			Seco 12	494	770	119	419	75	99	104	478	557	2.84	2.87
72 PANTANO Hieronyma chocoensis EUPHORBIACEAE	CO	.62	Verde	519	819	112	391	86	84	87	529	608	2.79	3.44
			Seco 12	914	1279	147	682	143	113	106	662	931	2.26	2.47
73 PARDILLO AMARILLO Terminalia amazonia COMBRETACEAE	VE	.65	Verde	480	804	137	425	67	106	116	624	712	1.96	2.16
			Seco 12	638	1218	140	652	103	155	167	818	999	2.08	2.40
74 PERHUETAMO Mouriri barinensis MELASTOMATACEAE	VE	.78	Verde	567	877	123	578	77	125	127	836	919	2.28	2.28
			Seco 12	927	1726	190	888	121	138	153	1086	1264	2.20	2.35
75 PIASTE Guarea sp. MELIACEAE	EC	.43	Verde	282	522	75	247	43	70		365	380	2.86	
			Seco 12	401	845	98	411	53	100		325	508	1.89	
76 PINO INSIGNE Pinus radiata PINACEAE	EC	39	Verde	116	252	45	98	26	46		191	198	2.74	
			Seco 12	293	664	76	290	70	85		264	328	1.58	
77 PITUCA Clarisia racemosa MORACEAE	EC	.51	Verde	465	864	106	427	83	94		498	519	2.32	
			Seco 12	620	934	106	498	76	102		487	679	2.15	

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	PERP.	CIZALLAMIENTO RADIAL	TAN.	DUREZA LADOS	EXTRE.	TENACIDAD RADIAL	TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
78 PLUMERO Vochysia lanceolata VOCHYSIACEAE	BO	.49	Verde	434	621	86	306	57	68	76	399	402	2.75	2.83
			Seco 12	597	943	115	536	79	89	87	539	683	3.34	3.25
79 PUMAQUIRO Aspidosperma macrocarpon APOCYNACEAE	PE	.67	Verde	638	955	148	522	96	113	122	739	737	3.90	4.12
			Seco 12	744	1142	145	678	119	134	141	886	931	3.62	2.91
80 PUNULA Quararibea asterolepsis BOMBACACEAE	CO	.45	Verde	328	452	80	222	36	48	60	232	329		
			Seco 12	596	767	107	422	70	77	92	351	458	1.83	1.72
81 ROMERILLO AZUCENO Podocarpus oleifolius PODOCARPACEAE	EC	.44	Verde	236	538	78	251	44	69		270	327	2.20	
			Seco 12	397	781	87	387	72	107		323	521	1.64	
82 ROMERILLO FINO Podocarpus rospigliosii PODOCARPACEAE	EC	.57	Verde	266	604	73	338	69	103		472	494	3.64	
			Seco 12	423	1016	96	473	86	116		452	677	2.05	
83 SAJO Campnosperma panamensis ANACARDIACEAE	CO	.37	Verde	323	579	115	244	34	58	57	186	217	1.57	1.46
			Seco 12	685	975	127	503	69	67	83	274	422	2.40	1.99
84 SAMAN Pithecellobium saman MIMOSACEAE	VE	.49	Verde	341	701	92	271	39	88	94	415	441	1.79	1.73
			Seco 12	382	784	94	436	60	109	115	443	498	1.06	1.26

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	COMPRESION PERP.	CIZALLAMIENTO RADIAL	CIZALLAMIENTO TAN.	DUREZA LADOS	DUREZA EXTRE.	TENACIDAD RADIAL	TENACIDAD TAN.
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
85 SANDE Brosimum utile MORACEAE	CO	.42	Verde	348	587	103	298	39	55	58	217	276	1.19	1.36
			Seco 12	655	928	113	528	82	58	78	311	454	2.24	2.18
86 SANDE Brosimum utile MORACEAE	EC	.40	Verde	250	505	85	247	26	55		222	277	1.52	
			Seco 12	407	800	111	400	40	66		265	415	2.17	
87 SANGRE DE DRAGO Pterocarpus vernalis PAPILIONACEAE	VE	.57	Verde	271	602	93	274	41	79	83	467	441	3.53	3.85
			Seco 12	478	1022	102	514	106	125	124	663	851	2.35	3.04
88 SANGRE DE VACA Licania sp. ROSACEAE	BO	.56	Verde	408	633	90	307	55	67	91	414	474	1.67	1.82
			Seco 12	643	1011	125	532	98	83	103	636	792	2.08	2.15
89 SAQUI SAQUI Bombacopsis quinata BOMBACACEAE	VE	.39	Verde	365	650	96	271	30	53	64	285	323	1.10	1.12
			Seco 12	448	751	98	392	40	48	51	186	194	.71	.74
90 SEBO Virola reidii MYRISTICACEAE	CO	.35	Verde	232	377	78	194	22	30	49	150	187	.96	.99
			Seco 12	449	711	113		46	38	57	223	366	1.61	1.32
91 SEIQUE Cedrelinga catenaeformis MIMOSACEAE	EC	.37	Verde	238	439	67	186	36	56		240	293	1.56	
			Seco 12	328	698	90	333	41	81		267	417	2.16	

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION PARAL.	COMPRESION PERP.	CIZALLAMIENTO RADIAL	CIZALLAMIENTO TAN	DUREZA LADOS	DUREZA EXTRE.	TENACIDAD RADIAL	TENACIDAD TAN
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	ER kg/cm²	ELP kg/cm²	ER kg/cm²	ER kg/cm²	kg	kg	kg – m	kg – m
92 SEREBO Schyzolobium parahybum CAESALPINIACEAE	BO	.40	Verde	270	377	59	192	28	59	58	187	228	1.34	1.42
			Seco 12	390	580	86	364	54	80	79	231	330	1.44	1.45
93 SOROGA Vochysia ferruginea VOCHYSIACEAE	CO	.37	Verde	375	608	90	273	44	58	66	285	323	1.91	2.05
			Seco 12	640	879	110	532	82	72	82	347	513	2.19	2.13
94 SUN SUN Didymopanax morototoni ARALIACEAE	VE	.36	Verde	218	426	94	191	12	45	56	184	234	64	68
			Seco 12	338	647	106	415	27	76	101	295	448	85	77
95 TACHORE Poulsenia armata MORACEAE	BO	.37	Verde	319	416	57	219	28	47	57	182	235	1.20	99
			Seco 12	445	587	85	394	50	69	71	254	418	1.35	1.36
96 TANGAMA Parkia sp. MIMOSACEAE	EC	.33	Verde	155	308	47	165	26	52		228	250	1.87	
			Seco 12	328	705	86	303	35	87		168	259	2.15	
97 TANGARE Carapa guianensis MELIACEAE	CO	.49	Verde	386	631	92	341	49	63	73	353	403	2.26	2.38
			Seco 12	663	1045	127	511	75	84	104	437	563	2.13	2.01
98 TORNILLO Cedrelinga catenaeformis MIMOSACEAE	PE	.44	Verde	352	579	108	287	57	76	88	388	361	2.97	3.09
			Seco 12	334	693	99	413	66	87	104	373	474	2.88	3.12

NOMBRE COMUN NOMBRE CIENTIFICO FAMILIA	PAIS	DEN. BAS. g/cm³	CONDICION	FLEXION ESTATICA			COMPRESION		CIZALLAMIENTO		DUREZA		TENACIDAD	
				ELP kg/cm²	MOR kg/cm²	MOE t/cm²	PARAL. ER kg/cm²	PERP. ELP kg/cm²	RADIAL ER kg/cm²	TAN. ER kg/cm²	LADOS kg	EXTRE. kg	RADIAL kg - m	TAN. kg - m
99 UCSHAQUIRO BLANCO Sclerolobium sp. CAESALPINIACEAE	PE	.38	Verde	292	488	91	238	30	61	69	305	296	3.54	3.61
			Seco 12	430	699	110	301	64	81	103	308	389	2.28	2.33
100 VERDOLAGO Terminalia amazonia COMBRETACEAE	BO	.65	Verde	575	848	104	383	90	92	108	581	588	4.16	3.72
			Seco 12	607	1088	135	584	124	111	129	911	1076	4.34	5.03
101 VIROLA Virola sebifera MYRISTICACEAE	VE	.37	Verde	196	378	76	189	16	41	58	175	231	.86	71
			Seco 12	282	624	100	354	27	56	77	216	344	.61	.56
102 YESQUERO Cariniana estrellensis LECYTHIDACEAE	BO	.87	Verde	484	720	83	349	79	85	101	524	519	3.19	4.05
			Seco 12	490	846	107	514	122	99	96	736	940	2.97	3.54
103 YUMBINGUE Terminalia guianensis COMBRETACEAE	EC	.61	Verde	491	844	115	356	63	90		554	580	3.76	
			Seco 12	578	1239	143	546	78	142		583	787	3.17	
104 ZAPATERO Peltogyne porphyrocardia CAESALPINIACEAE	VE	.88	Verde	801	1221	169	684	129	147	181	1524	1364	2.90	3.23
			Seco 12	1068	1785	199	963	210	210	232	1931	1814	2.82	3.12